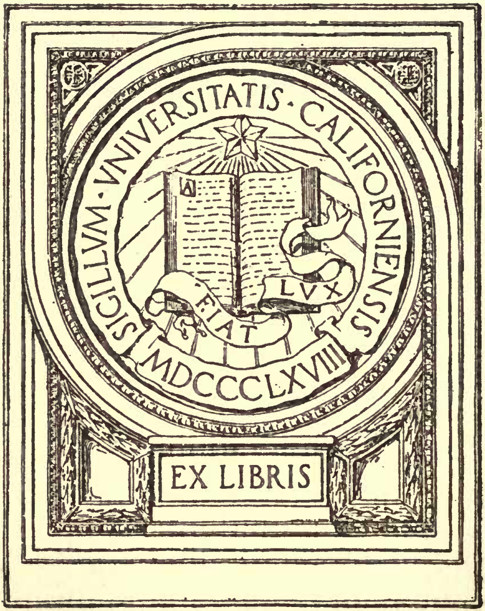

WEATHER SCIENCE

HIGH STRATUS AND CIRRO-STRATUS CLOUDS.
(Photo by Capt. Wilson Barker, F.R.S.E., F.R.Met.Soc., &c.)

Frontispiece.

WEATHER SCIENCE

AN ELEMENTARY INTRODUCTION
TO
METEOROLOGY

BY

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Blue

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1911

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PREFACE

In the preparation of this work I must acknowledge my indebtedness to previous writers on the subject, and to the admirable Text-books, both popular and scientific, that have appeared from time to time. Amongst these I may mention the volumes by Dr R. H. Scott and Mr Abercromby in the International Scientific Series, Dr Waldo's "Modern Meteorology," Dr Hann's "Meteorologie," my friend Mr Inwards' "Weather Lore," Flammarion's "L'Atmosphère," Dr Archibald's and Mr G. F. Chambers' popular works, as well as the transactions and journals of Meteorological Societies which have been consulted and referred to in due course. My indebtedness is also great to the late Commander M. F. Maury's "Physical Geography of the Sea," to the Text-books of Professor S. P. Thompson and Dr R. W. Stewart on Electricity, to the late Dr C. A. Young's "General Astronomy," etc.

For the illustrations I am indebted to the kindness of Captain Wilson Barker, of H.M.S.

training ship *Worcester*, who sent me seven photographs of typical clouds, taken by himself, one of which appears as the frontispiece; whilst Mr Inwards has permitted the reproduction of his plate of cloud forms, as well as the illustrations of Greenwich and Kew Observatories, and the Temple of the Winds, Athens; to Dr H. R. Mill, head of the British Rainfall Organisation, I owe the Rainfall Map that appears in chapter iv. Messrs Casella, Pillischer and Short and Mason have also kindly supplied illustrations of some of the instruments, barometers, thermometers, etc., described in the chapters on instruments. To all of these gentlemen for their help in these and other ways, as well as to others, my thanks are due.

In addition I wish to express my gratitude in especial to Dr H. R. Mill and Mr Inwards for their kindly advice and recommendations during the course of publication.

F. W. HENKEL.

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WEATHER SCIENCE

CHAPTER I

INTRODUCTORY — ANCIENT IDEAS — THE BAROMETER AS A "WEATHER GLASS" — DAWN OF MODERN METEOROLOGY — CYCLONES AND ANTICYCLONES — THE EARTH: ITS SIZE, SHAPE, AND MOTIONS— THE ATMOSPHERE.

EVERY one thinks that he or she knows something about the weather, and its vagaries, real or assumed, are an unfailing subject of conversation, affording ample opportunities for the indulgence in the Englishman's privilege of grumbling. Yet, notwithstanding the multiplicity of weather saws and sayings, the enormous mass of statistical details collected by the industry of countless observers in our own and other countries and published in ponderous tomes, whose covers no one ever opens, by Governmental departments and learned societies, it must be confessed that the *science* of the weather is as yet in its infancy. Very little has been done in the way of utilising "the dry masses of figures which accumulate year after year, and lie absolutely idle in yearly volumes, unread and unstudied," but still the game of accumulation goes on as merrily as ever. However, of recent years some attempts have been made to arrive at a better state of things; our knowledge, not merely of the bottom of the "ocean of air" in which we live, but also of portions of its upper regions, has been increased by the judicious flying of kites with self-recording instruments of precision, and much important information as to the distribution of temperature, moisture, etc., in those hitherto unknown heights has been obtained. The application of dynamical methods by Bezold and others, the development of theories of atmospheric circulation, the improvement of instruments and the establishment of regular meteorological observatories, not only in the lowlands but also in mountain regions, these and other things have all helped in throwing light upon some of the obscurer problems of the science. The complexity of the subject, however, seems to give little hope that the ideal of deducing all weather changes from the knowledge of the variations in the amount and direction of the solar radiation, in their effect upon the mixture of air and water vapour of which our atmosphere consists, will be soon realised.

For a long time to come Meteorology must be regarded as a science of pure observation, and our knowledge of it confined to generalisations obtained with more or less exactness as the result of these observations. In early days, Meteorology (from the Greek *τὰ μετέωρα,* things above), included not only the study of the atmosphere, its clouds and weather changes, but also such things as comets and shooting stars (or *meteors*, as they are distinctively called), which, being now known to be extra-terrestrial phenomena, are removed to the domain of Astronomy. Accordingly we find in Ptolemy's "Almagest," the greatest work of the ancient Greek astronomy, no mention of comets at all, the latter being regarded as mere temporary exhalations or vapours from the ground drawn upwards, and burning when they reached the "region of fire." Aristotle, perhaps the most universal genius who ever lived, whose works and ideas on almost every subject were held in the utmost reverence till about two centuries ago, considered that the atmosphere is divided into three regions. The first region is that in which animals and plants live, supposed to be immovable like the earth on which it rests; the second is an intermediate region, intensely cold; the third region, contiguous to the region of fire, or the heavens, partakes of the diurnal motion of the latter. Vapours arising from the earth ascend to this region and are heated, engendering igneous *meteors* and comets. A characteristic feature of these ideas is the slender basis of fact upon which they rest.

Where experiment or observations were few, or wanting altogether, the ancient writers seem to have found no difficulty in supplying the deficiency by means of vivid imagination. A writer of authority made a definite statement, and his word passed for ages unimpeached, no attempt being made to ascertain whether the results of experiment agreed with the predictions of theory or not. In this way there have arisen fancies as to the connection between the "changes" of the moon and weather change, still widely believed in, though absolutely without foundation in fact; others, after the spirit of the old astrologers, have brought in the planets, the infinitesimal variations in the sun's light and heat accompanying the greater or less spottedness of his surface, etc., as efficient causes. All such speculations, by attributing specific and different actions in different regions of the earth, bring their own refutation. Whatever influence, for instance, a sun spot may have upon terrestrial conditions, it is difficult to believe that it can cause extra heat in one region, deficient rainfall in another, and specially fine weather in a third. So far we may be satisfied to look to nearer causes for such variations, and it must be confessed that the complexity of the subject is such that we can hope only for slow progress in our knowledge in this respect.

The science of weather predictions, and the results obtained, will be alluded to in the course of this work in further detail. So far, however, greater success has been obtained in *average* results than in furnishing information which is available for any *specific* short interval, such as the total rainfall on a given day, or the *actual* temperature at a given place.

An instance of the uselessness of average results as to mean temperature and other weather conditions in enabling predictions to be made for any specific future occasion is given by Mr Abercromby in his well-known book on the "Weather." Nearly a hundred years ago, Napoleon, on the eve of his invasion of Russia, requested Laplace to calculate when the cold set in severely over that country. The latter found that on *the average* it did not set in hard until January. "Napoleon made his plans accordingly, a sharp spell of cold came on in December, and the army was lost." In a similar manner we have found by long continued series of observations the *mean* height of the barometer for every day of the year and almost for every hour of the day at most inhabited places on the earth's surface, but this gives no information whatever as to what will be the *actual* height at any particular moment, in fact this is almost bound to be either higher or lower than the *mean* value.

The old weather prognostics, many of which we inherit from classical days, and some from yet earlier periods, have been handed down into all European languages, and are still of great value. Most of the saws and sayings relating to the approach of rain, perhaps the most important point which concerns all, young and old, rich and poor alike, are well known, and their general accuracy has been often testified to, though it is only within recent years that some reasons for their verification as well as explanations of their occasional failure have been forthcoming.

The invention of the barometer nearly three centuries ago, and the consequent knowledge of the variations in atmospheric pressure, led to the discovery that, *on the whole*, the mercury fell for rain and windy weather, and rose for fine, being generally low when the conditions were unfavourable, and high when fine settled weather prevailed. Hence arose the designation of this instrument as a "weather glass," and the conventional but incorrect notation still to be met with even now, some makers alleging that the public will not buy barometers without these indications. Yet a very short series of observations will suffice to show that rain sometimes falls with a *high and rising* barometer, and there are frequent occasions of good weather when the "glass" is low. Of more scientific value are the instructions given in the well-known Fitzroy or "fishery" form of barometer, these embody the results of careful observations.

In our latitudes the barometer usually falls with S.E., S., or S.W. winds, and rises with W., N.W., and N. ones. Thus most rain coming with southerly and south-westerly winds, owing to their having blown over the ocean before reaching us, this explains the ordinary statement, but since rain sometimes comes with a northerly wind also, the rise of the barometer often deceives those who expect fair weather from the latter circumstance.

The method of synoptic charts, giving the conditions of temperature and pressure, direction and force of the winds, etc., over large areas of the earth's surface (as illustrated by the daily diagrams published by the Meteorological offices of this and other countries which are reproduced in the newspapers), constituted a distinct advance in the science of weather predicting. Telegraphic information from a number of stations is transferred to an outline map. Lines are drawn through all places having the same barometric height, these *isobars*,[1] as they are called, being usually marked at intervals of $\frac{1}{10}$ inch or 2 mm. (5 mm. = ·2 inch very nearly) of the mercurial barometer, and from the nature and present arrangement of these lines important information as to impending changes in weather may be easily gathered.

The direction and force of the wind at various places is marked, as also the temperature, at a given time, lines drawn through places having the same temperature being known as isothermal lines, or simply "isotherms." A general rule

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[1] All places in the neighbourhood where the pressure is for the moment the same are on the same isobar (ἴσος, equal ; βαρύς, heavy).

governing the relation between the direction of the wind and the position of the isobars was enunciated by Buys Ballot in 1860, and is accordingly known by his name. "If one stands with his back to the wind, the barometer will be lower on his left hand than on his right." Thus when the barometer is higher to the north than to the south, the wind will be east, when it is higher to the east than to the west the wind will be southerly, and so on. It is evident, however, that this knowledge can only be possessed by an observer who knows the conditions at other stations than his own. The movement of air being due to the difference of pressure at different regions, it follows that where the "gradient" is small, or the isobars are *far apart*, the wind will be in general slight; when, on the other hand, the isobars are close together, there will be more wind, and a "serious storm may be expected when there is a difference of half an inch of pressure between two neighbouring stations." Speaking generally, it may be said that the force of the wind will not exceed that of a "strong" or "fresh" breeze, unless the gradient exceeds 0·02 inch for a distance of 15 geographical miles, approximately equal to 2 mm. per degree of latitude (Abercromby).

Seven different forms of isobars are usually distinguished, of which two, the "cyclone" and the "anticyclone," are the most familiar to ordinary readers. The former is a region of low pressure, surrounded by more or less nearly circular isobars, hence the name (from the Greek κύκλος, a circle). These, however, usually have the form of somewhat elongated ovals, and are by no means concentric. At or near the centre of the innermost oval is the point of lowest pressure, spoken of as the centre, or "eye," of the cyclone. Generally speaking, cyclones are in fairly rapid motion, in this country usually from S.W. towards N.E., and the wind rotates round the centre in the positive or "counter-clockwise" direction (that contrary to the direction in which the hands of a clock move), its intensity depending on the closeness of the isobars, being nearly proportional thereto. Occasionally cyclones are stationary, break up or move in an unexpected direction—hence one cause of the failure of predictions founded on the supposition that they will follow their usual course. The cyclones which cause the much dreaded tropical storms are of the same nature, and differ principally from those we experience in these latitudes, in the much greater variations of pressure within a short distance and the consequent greater violence of the wind. In our country the velocity of a cyclone centre may vary from 10 to 70 miles per hour, and, as we have said, its motion is usually eastward, though a few move in the westerly direction, whilst others are stationary. The air to the front is usually warmer than that in the rear, and thus gives rise to the well-known close, "muggy" sensation, that in the rear is characterised by a brisk, exhilarating feeling. The anticyclone, on the other hand, is a region of high pressure, surrounded by isobars usually much further apart than those of a cyclone, and consequently covering a larger area. Light winds circulating in the "clockwise" direction; or calms, prevail, and sometimes for days or even weeks there is practically no motion of the system at all, until it breaks up or moves slowly on. The ordinary features of weather are a clear sky and dry air, varied sometimes by a few light showers, in summer a hot sun, in winter fog and frost. The other forms of isobars will be dealt with more in detail later on in the course of this work (chap. v.).

The earth, "our common mother," the standpoint from which we view the rest of the universe, is one of a number of more or less spherical bodies of varying sizes moving round a centre, known as the planets of the solar system. It is the third in order of distance of the planets moving round the central body, and its motions may be roughly divided into two principal ones, the diurnal rotation on its axis, causing the succession of day and night, and the annual motion round the sun, causing (in our latitudes) the phenomena of the seasons. In shape the earth is not strictly of the form of any regular geometrical figure, but approximates to an oblate spheroid of revolution, *i.e.*, a figure like a sphere (the distance of every point of whose surface from the centre is the same), but with a greatest and least diameter, round the latter of which it turns once in twenty-four (sidereal) hours. The least diameter (polar) is as nearly as possible 7,899 miles, the greatest (equatorial) diameter is 7,925 miles, so that the deviation from exact sphericity, or the polar flattening, as it is sometimes called, is not great. Neither the elevation of mountains, nor the depression of the sea bottom, nor even the polar flattening, bear any considerable proportion to the whole size of the earth, the highest mountain never rising more than 6 miles above the general surface, whilst the deepest seas have less than that distance from surface to bottom, and the difference between equatorial and polar diameters (25 miles) is but a small fraction of either, so that a model made accurately in wood would be undistinguishable by the eye from an exact sphere.

The diurnal rotation on its axis causes a point on the Equator (circumference $7{,}925 \times 3{\cdot}1416$ miles $= 25{,}000$ miles nearly) to move over more than 1,000 miles per hour, points in higher latitudes having slower motions, till at the Poles there is no rotation at all.

In the latitude of London ($51\frac{1}{2}°$ N.) the speed of rotation is about 600 miles per hour, this varying directly as the cosine of the latitude, being at its maximum on latitude 0° (equator) and zero at latitude 90° (poles, where $\cos 90° = 0$). The rotation of the earth on its axis, besides causing the succession of day and night, rising and setting of the stars, etc., has a most important meteorological effect in causing the phenomena of the "trade" and "anti-trade" winds, the deviation of air currents produced during their movement from places moving more quickly to others of slower rotation, and *vice versâ*, which will be dealt with later on in the course of this work.

In addition to this motion of rotation the whole earth has a progressive motion round the sun, completing one circuit in the course of a year, moving in a path which is approximately circular (in reality slightly oval), and which lies in one plane (the ecliptic), which makes an angle of about $23\frac{1}{2}°$ with the perpendicular to the axis of rotation (the Equator); or in other words, the inclination of the Equator to the ecliptic is this angle, whose mean value on 1st January 1910 is given in the *Nautical Almanac* as 23° 27′ 3·58″, diminishing at the rate of 0·468″ per annum. These planes intersect in two points, called technically the first point of Aries and the first point of Libra, the sun appearing from the earth to be in the former on 21st March, when his longitude is said to be zero, and in the latter on 23rd September (approximately, varying slightly through the calendar arrangement of leap year, and the slightly unequal apparent motion of the sun), or perhaps, since it is the earth that moves and not the sun, it would be more correct to say that the earth is in "Libra" on 21st March and in "Aries" on 23rd September.[1]

Since, after all, all motion is in reality relative, it is not only convenient, but, so far as we are concerned, correct, to use the current language. Thus between 21st March and 23rd September the sun's position is on one side (north) of the equinox, whilst for the rest of the year he is on the other side (south) of that plane. When in the celestial Equator, which we may regard as the indefinite prolongation of the plane of the terrestrial Equator to the heavens, the sun is everywhere above the horizon for twelve hours, and for an equal time of day below it, and these times are consequently called the equinoxes (Latin: *equus*, equal; *nox*, night), day and night being equal. After this, from 21st March to 21st June, the sun's distance from the Equator northwards becomes greater and greater; the "days" in our latitude, or times

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[1] The signs *Aries* and *Libra* are now distinct from the constellations of those names, and are *now* approximately situated in the preceding constellations *Pisces* and *Virgo*. The "first point of Aries" is not very near any bright star, but not very far from the fourth magnitude star ω Piscium; the "first point of Libra" is between the double star β Virginis and the star η of that constellation, both of the third magnitude. Both these points, however, are slowly changing in position owing to "Precession of the Equinoxes."

during which he is above the horizon, become longer and longer; the "nights," or periods when he is below, becoming correspondingly shorter. After this, reaching his greatest distance north of the plane of the Equator ("first point of Cancer"), his distance from that plane gradually diminishes, till on 23rd September he is again in the celestial Equator. The days and nights are once more equal, the former having been gradually growing shorter and the latter longer from 21st June to 23rd September. After this time the sun's apparent motion carries him south of the Equator; the days are now shorter than the nights, the former continue decreasing, the latter increasing, till the extreme values, both for the sun's angular distance (south) and the length of these periods, are attained on 21st December (shortest day in our hemisphere). The varied phenomena of the seasons and the different altitudes of the sun, relative length of day and night in different parts of the globe, are fully explained in most geographical and astronomical works, so that we need not go much into detail here. It will suffice to say that since the days *are longer*, and *the altitude of the sun* greater in summer than in winter, we have here the *primary* cause of the difference of temperature between those seasons; whilst in spring and autumn both the length of the day and the altitude of the sun have intermediate values, and, as is well known, these seasons are colder than summer, and (in general) warmer than winter with us. Thus the first and most general cause of the difference in temperature at different times of the year in our country is roughly indicated, whilst the difference between the temperature in our latitudes and that experienced in "hot countries" nearer the Equator is primarily due to the more nearly vertical position of the sun in the latter regions. As one writer puts it, the *same amount of heat* is spread over a larger area, and so each *spot* receives less.

At all places between latitudes 23½° N. and 23½° S., which zone, bisected by the terrestrial equator, is known as the Torrid Zone, the limiting latitudes, 23½° N. and 23½° S. being known as the Tropics of Cancer and Capricorn respectively, the sun is in the zenith or vertical at some time or other during the year, and its altitude, when highest, at noon is never *less* than $90° - 47° = 43°$, whereas its *greatest* altitude above the horizon in the latitude of London (51½°), though 62° on 21st June, is less than this on every other day of the year, being only 15° on 21st December. Everywhere throughout the Torrid Zone the length of the time the sun is above the horizon never varies greatly from twelve hours, the night being of about the same length. On the Equator itself the days and nights are *always* (theoretically) of equal length (neglecting the effect of refraction by the atmosphere, which is always to slightly extend the former at the expense of the latter, and of which we shall soon have to speak), but further north and south there is a slight variation.

At the Tropic of Cancer (23½°), for example, the sun is vertical on 21st June, when he is said technically to enter the sign of that name, and the length of the day has then its greatest value, thirteen and a half hours, whilst the night is only ten and a half hours long. Conversely, on 21st December the sun has his least altitude at noon, only 43°, and the day is only ten and a half hours long, the night being then thirteen and a half hours long. Between latitudes 23½° N. and S. and latitudes 66½° N. and S. respectively, the sun's greatest altitude varies from 90° (when he is in the zenith), to nothing (when he is on the horizon), and the length of the day undergoes corresponding variation. Everywhere within these zones, the "Temperate Zones," he rises and sets at least once every day, though, theoretically, at the summer solstice he barely touches the horizon at midnight, for latitude 66½°, whilst at the winter solstice he scarcely rises at all.

Between latitudes 66½° N. and S. and the respective Poles—the "Frigid Zones"—the sun has never an altitude greater than 47°, about half-way between the horizon and the point overhead, so that his rays always fall more or less obliquely; and whilst at one time of the year (during summer of each hemisphere respectively) he is visible near the horizon at the time that would be midnight in lower latitudes, and the phenomenon of the "Midnight Sun" is seen, at another time he does not rise at all, and perpetual night, lasting for a longer or shorter period (during the winter of each hemisphere), arises. At the Poles the sun is alternately visible and invisible for about six months at a time (but *see* "Refraction" by the atmosphere, *infra*), but his greatest altitude never exceeds 23½°, or its value at noon on 8th February in the latitude of London, so that his rays at no time fall more than very obliquely, though his long continuance above the horizon will help to raise the temperature above what might otherwise be expected. The phenomena at either Pole will be somewhat different from anywhere else on the earth, *so that the measurement of the sun's apparent altitude will afford a certain test as to whether the observer is, or is not, in latitude* 90°. If, now the sun's altitude be carefully measured when he is in one part of the sky, and again twelve hours later, the corrected readings, after allowance for refraction and instrumental errors, differ only by the amount of the sun's change of declination during that interval, as given by the *Nautical Almanac*, then the observer may be confident that he is very close indeed to the position of the terrestrial Pole.

Though, as we have just stated, the primary cause of the different temperatures prevailing in different parts of the earth is to be looked for in the unequal amount of heat directly received from the sun, yet the relative distribution of land and water cause the actual values to be very different from what would otherwise be the case. Water having a greater specific heat than almost any other substance (that is, more heat is required to raise its temperature by a given amount than is the case for land surfaces, and more heat is given out by it in cooling through the same degrees of temperature than do land masses), the heat of summer is mitigated and the cold of winter moderated by the presence of large masses of water, for the lands adjoining them—hence arises the difference between "insular" and "continental" climates. Water covering $\frac{7}{10}$ths of the earth's surface, whilst of the $\frac{3}{10}$ths surface uncovered by water the greater part lies in the Northern Hemisphere, we find very considerable differences in temperature between points in corresponding latitudes, which receive almost exactly the same amount of sun heat, directly. As an equally important cause may be mentioned the existence of warm and cold currents, such as the Gulf Stream flowing from the Central Atlantic towards Western Europe, a warm current conveying some of the heat received by the tropical regions to the latter, the "Humboldt current" of the Southern

Pacific and "Polar currents" helping to cool the lands towards which they flow.

But the earth is not merely a mass of land and water, otherwise neither man himself nor the science of meteorology could exist. Above and around it, to an unknown height, extends the atmosphere or "ocean of air," a gaseous envelope. The main constituents of this atmosphere are the gases oxygen, nitrogen, argon and carbon dioxide, with a variable amount of water vapour, and small traces of ammonia, nitric acid, etc. The density of this atmosphere is greatest at the earth's surface, and rapidly decreases as we go upward, but no certain limits can be assigned beyond which we can positively assert that there is no air at all, though at a height of above 100 miles from the surface the quantity of air must be very small indeed. Being a gas, or rather a mechanical mixture of a number of gases whose relative proportions vary very slightly at different times and places, the atmosphere possesses elasticity, *exerts pressure*, and is easily affected by changes of temperature. As a fluid never in equilibrium, it is in constant motion, and the consideration of its motions under various influences forms the main part of our study. Were the whole atmosphere of *uniform density*, equal to that which it has at the surface of the ground, its height would be only about 5 miles, and this height (26,000 feet) is sometimes called the height of the "homogeneous atmosphere"; this would produce a pressure equal to that actually existing at the surface of the earth, which pressure on every square inch is about equal to that produced by the weight of a column of mercury 30 inches high and 1 square inch in cross section. In terms of the C.G.S. system (in which the *centimetre* is the unit of length, the *gramme* the unit of mass, the *second* the unit of time) the air pressure on each square centimetre of the ground is about equal to that of a column of mercury 76 cm. high and 1 sq. cm. in cross section, upon an area of 1 sq. cm. at its base.

This pressure is conveniently known as *atmosphere* of pressure; in English measure this equals about 14·7 lbs. per square inch. The pressure higher up is less, and decreases gradually as we ascend. It is commonly and conveniently measured by the barometer (βάρυς, heavy; μέτρον, a measure), perhaps the most important of all meteorological instruments.

Though, as we have stated, the *mean* pressure is as above, yet its actual value is always varying, and the study of these changes involves much of our science, sudden changes of pressure almost always accompanying changes of weather, whilst fairly settled or slowly changing conditions invarably indicate settled weather.

Owing to the presence of the atmosphere, we do not see external (heavenly) bodies exactly in their true positions. Rays of light coming from the sun, moon, or a star have their directions changed by this action, which is called "refraction," just as we observe the image of a straight stick immersed partly in water to be apparently *bent* at the surface, the part below being seen raised above its true position. In a similar manner the sun and stars are seen above the position they would otherwise occupy in the sky, by a variable amount depending on their altitude above the horizon, and (in a less degree) on the temperature and other conditions of the air.

There is an important difference, however, between refraction by the atmosphere and that produced by a fluid such as water. The latter being homogeneous, a ray of light entering it in any direction not perpendicular to its surface, is bent in a *definite direction*, making an angle with its original course ("*sine* of angles of incidence and refraction in a constant ratio to one another"), and pursues its new course without further change so long as it remains in the water, whilst a ray of light entering our atmosphere from outside undergoes a *gradual and increasing* deviation as it enters more and more dense air, whereby it is made to traverse a slightly curved path, and the celestial body is seen in the direction of the tangent to the point of the curve which reaches the eye of the observer. The density of the lower atmosphere being greater than that of the upper air, the refraction is greater for the former. As a result of refraction the sun and moon are seen above the horizon at a time when they are really below it. The time of sunrise in our latitudes is accelerated, and that of sunset is *retarded*, and so the day is lengthened by from five to eight minutes. In more northern latitudes this difference is yet greater, whilst in the Arctic Regions the result is that the length of "perpetual day" is increased by several "days," and that of "perpetual night" is shortened by a corresponding amount.

When the sun and moon are near the horizon, we notice that they are distorted from a circular form into ovals, and are usually of a reddish colour. The former effect is due to the fact that the amount of refraction changes rapidly near the horizon, being greater below than above. Thus the lower edges of these bodies are raised more than the upper ones, so that the vertical diameter is diminished. The horizontal diameter is not affected, and so the sun and moon appear to be *oval* and not *circular*. Their reddish colour is due to absorption. White light is composed of all the "colours of the rainbow"—red, yellow, green, blue, violet, etc., — and of these, the green, blue, and violet (the shorter "waves") are more readily absorbed by the atmosphere, or rather its *vapours* (for pure dry air exercises scarcely any absorption), than the red and yellowish rays (which are longer). Thus this process of selective absorption results in the loss of a greater amount of the blue and violet rays, and so the sun and moon, when seen low down near the horizon, appear reddish or yellowish rather than white, an effect seen also when the sun shines through a "November fog."

Twilight is also a phenomenon due to the presence of our atmosphere. For a short time after the sun sets (and before it rises) some of its light falling in the upper regions clouds, etc., is reflected downwards, and thus gives illumination to the lower atmosphere and ground. It is not certain whether this reflecting power is due to the gases of the atmosphere or to the presence of dust particles, water vapour, and possible ice crystals existing in it. So long as the sun is not more than 18° below the horizon of any place, some light will thus be received by reflection from the upper atmosphere, and thus the length of the day will be appreciably increased. It thus happens that from the latter part of May till the middle of July, though the sun is below our horizon at London for more than seven hours out of the twenty-four, there is no real night during that period, though at midnight the amount of light received from the sun is at times very small. The red tints of sunset are due to a similar cause to that from which arises the red colour of the rising and setting sun.

The generally diffused light of the sky in the daytime is also due to the presence of the atmosphere. If there were no atmosphere the stars would be visible by day as well as by night. The scattering and reflection of light by the air, its vapours and dust particles, give rise to a general illumination, strong enough to render the more feeble illumination of the stars invisible, except under special circumstances. The *blue colour of the sky* is also due to the scattering of light by small particles in the air, the red, as we have just seen, being transmitted; though much of the other radiation forming white light is absorbed, a portion appears to be reflected. It is by no means certain what substances are most effective in this. Lord Rayleigh thinks that fine salt particles floating in the air, or even the oxygen itself may be the cause. The presence of metallic meteoric dust has also been suggested as an important factor in producing this coloration. Thus, apart from its essential character as a supporter of life and every kind of combustion, the other services rendered by our atmosphere are many and important. To its presence is due much of the varied play and coloration of the inorganic world, the brilliancy of the clouds, and the wondrous tints of sunrise and sunset; the blue of the sky, so different from the inky blackness that would prevail were it absent, the gradual coming on and fading away of illumination in the morning and evening, instead of the instantaneous appearance of day and night respectively, are all results of its presence.

As a storehouse of the solar heat after it has reached the earth, the atmosphere is a most important meteorological agent. The sun's rays pass fairly freely through the air, only a small portion being absorbed by the vapour of water and traces of carbon dioxide (oxygen and nitrogen, the main constituents being almost perfectly diathermanous or "transparent" to radiant heat), and reach the surface of the ground or the waters. Most of these rays are then *reflected*, but in the act of reflection they are changed somewhat in character, and are then *largely absorbed* by the water vapour and the clouds instead of going back into outer space again. Part of these absorbed and reflected rays are again reflected downwards by the clouds, and so in large measure the heat is kept in, and remains as a permanent gain to the earth. On a cloudy night the air never becomes so cold as on a clear one, when there is less vapour in the atmosphere. In the latter case the heat reflected from the ground not being stopped passes more or less completely out, and as none comes in from outside, the temperature rapidly falls. Theories of dew and hoar frost formation depend upon an action of this kind, as we shall see in a later chapter.

Until quite recently all observations were confined to the denser layer of atmosphere in immediate proximity to the ground, and nothing was known as to the conditions prevailing in the upper regions. At a few mountain observatories some information had been obtained, occasional balloon ascents were made, and inferences drawn from the behaviour of the upper clouds, which revealed the presence of currents whose velocity much exceeded anything known to occur near the surface of the ground. Of late years, however, by means of kites sent up with self-recording instruments, much important information as to these hitherto unknown regions has been obtained, some account of which will appear in a later chapter of this work.

It has been already stated that there is no *definite* knowledge as to how far the atmosphere extends upwards. The density, however, decreases very rapidly, and there can be very little air at a greater height than about 50 miles. Observations of the duration of twilight indicate about this limit, but meteorites visible only to us by their heating to incandescence by friction against a resisting medium, have been seen at a height of 100 to 150 miles, so that a very small amount of air must exist at a greater height than is shown by the twilight observations. The aurora, a phenomenon probably due to electric discharges in the rarefied upper air, is not often known to exist at a greater height than about 40 to 50 miles. Though the extension of the atmosphere upwards is to a small degree uncertain, yet from a knowledge of its specific gravity and pressure at the surface, its total weight may be inferred.

One cubic foot of dry air, measured at the temperature of freezing water (32° F.) and under the barometric pressure equal to 30 inches of mercury, weighs 1·3 ozs. or 565 grains, more exactly, the exact experiments of Jolly giving for the weight of 1 litre of air at 0° C. (32° F.), and under the pressure of 760 mm. (of mercury) values varying between 1·30493 and 1·30575 grammes. The total weight of the atmosphere of the earth resting on its surface was given by Sir John Herschel as $11\frac{2}{3}$ millions of pounds or 5·3 trillions of kilogrammes ($5{\cdot}3 \times 10^{21}$ grammes). The composition of this air is remarkably constant. Though a mechanical mixture, and not a chemical compound, the proportions of its ingredients vary very slightly, wherever the air may be collected. Of the four principal constituents, oxygen, nitrogen, argon, and water vapour, only the last varies to any appreciable degree. By volume, the oxygen forms 20·9 per cent., nitrogen 76·0 per cent., argon 1 per cent., whilst the water vapour varies from 1 per cent. to 4 per cent., when the air is very damp. The carbon dioxide, whose amount in pure country air is less than 0·03 per cent., sometimes may exceed 0·07 or 0·08 per cent. in the air of a town, whilst in badly ventilated crowded halls it may reach to 0·20 per cent., or even more. Though these different gases differ considerably in density, water vapour being the lightest, and carbon dioxide the densest; owing to diffusion, the proportion of these ingredients does not sensibly vary at different altitudes. The heavy carbon dioxide is carried upwards, and the lighter water vapour downwards by the action of the same principle. Nevertheless, there is a tendency for the lighter gases to spread more rapidly upwards, and the heavier to remain below, so that it has been supposed that the absence of hydrogen, the lightest of all gases, from our atmosphere in a free state, is due to the upward diffusion whereby it has "got beyond the power of recall by gravitation." But all such speculations depending as they do upon the uncertain indications of the "kinetic theory" of gases, are to be deprecated, and we should rather wait for further experimental knowledge than attempt to supply its place by premature hypotheses. Within the last few years several new gases previously unknown have been discovered (argon, xenon, crypton, etc.), and hydrogen has been detected in the *fumerolles* or jets of steam of Tuscany, and also in the human breath under certain conditions (Thorpe).

The following quotation from the works of the late Dr Buist of Bombay may fitly be inserted in this place:—

"The atmosphere is a spherical shell which surrounds our planet to a depth which is unknown to us, by reason of its growing tenuity, as it is released from the pressure of its own superincumbent mass. Its upper surface cannot be nearer to us than 50, and can scarcely be more remote than 500 miles. It surrounds us on all sides, yet we see it not; it presses on us with a load of 15 lbs. on every square inch of surface of our bodies, or from 70 to 100 tons on us in all, yet we do not so much as feel its weight. Softer than the softest down—more impalpable than the finest gossamer—it leaves the cobweb undisturbed, and scarcely stirs the lightest flower that feeds on the dew it supplies; yet it bears the fleets of nations on its wings around the world,[1] and crushes the most refractory substances with its weight. When in motion its force is sufficient to level the most stately forests and stable buildings with the earth—to raise the waters of the ocean into ridges like mountains, and dash the strongest ships to pieces like toys. It warms and cools by turns the earth and the living creatures that inhabit it. It draws up vapours from the sea and land, retains them dissolved in itself or suspended in cisterns of clouds, and throws them down again as rain or dew when they are required. It bends the rays of the sun from their path to give us the twilight of evening and of dawn; it disperses and refracts their various tints to beautify the approach and the retreat of the orb of day. But for the atmosphere sunshine would burst on us and fail us at once, and at once remove us from

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[1] This was written before the days when the atmosphere is polluted by the reckless waste of the stored up accumulation of ages; the consumption of thousands of tons of coal, to satisfy the cravings of a few would-be "record breakers," to save a few hours of their worthless time, regardless of all other circumstances.

midnight darkness to the blaze of noon. We should have no twilight to soften and beautify the landscape, no clouds to shade us from the scorching heat, but the bald earth, as it revolved on its axis, would turn its tanned and weakened front to the full and unmitigated rays of the lord of day. It affords the gas which vivifies and warms our frames, and receives into itself that which has been polluted by use, and is thrown off as noxious. It feeds the flame of life exactly as it does that of the fire—it is in both cases consumed, and affords the food of consumption; in both cases it becomes combined with charcoal, which requires it for combustion, and is removed by it when this is over."

The temperature of the atmosphere is perhaps of more immediate interest to our physical well-being than almost any other phenomenon, for, as it has been well put by an esteemed friend of the writer, "the struggle for existence is essentially, after all said and done, a struggle with cold." Warmth is more than food to the body, and in fact the need for the latter is the want or otherwise of the former, food being the fuel of the living "steam-engine at work." Many eminent meteorologists, too, consider the determination of temperature as the most important of all observations in the science, for it is to the unequal heating of different parts of the atmosphere, the sea, and the land, mainly by the sun's radiation, that almost all circulation and other movements are primarily due. From these arise the equatorial warm currents, both ærial and aqueous, the polar colder streams which take their places, the differences of pressure in different regions (modified somewhat by the earth's rotation), the trade winds and the anti-trades, the various regions of high and low pressure (anticyclones and cyclones), etc. Of minor import, if indeed the action is certainly detectable, is such tidal effect as is produced by the unequal attraction of the moon and sun upon different parts of the atmosphere. Changes in the number and intensity of sun spots, and other signs of solar activity have relations more or less direct with the phenomena of terrestrial magnetism, the Aurora (Borealis and Australis), magnetic storms, etc., and have been suspected by some to have a yet more intimate connection with weather conditions. Upon this point prejudice has hitherto perhaps come more into play than sober deductions from ascertained facts, one party rejecting as preposterous the notion that there can be any such connection between the greater or less development of sun spots and local weather conditions, the other party as unhesitatingly accepting it. Attempts have even been made to show that such things as the recurrence of famines, floods, excessive or deficient harvests, commercial "booms" and panics, are all intimately related to the sunspot period.

Such evidence as we have so far is of such a nature that altogether contradictory results have been arrived at by different investigators, but some short account of these will be dealt with in a later chapter of this work (chap. xv.). In the "Dark Ages" the immediate influence of not only the sun and moon, but of all the heavenly bodies, upon terrestrial phenomena, was generally believed in. The phenomenon of dew was considered a product of the stars; one planet "produced" rain, another gave fine weather, and so on. Even within comparatively recent times the "wild fancy" of Bishop Whiston attributed the Noachian deluge to the near approach of a "watery comet," which later on is to destroy the world by fire! This was offered to the world in Newton's day!

Till little more than two centuries ago comets and "shooting stars," still called meteors, were considered as terrestrial phenomena, and were accordingly not considered by astronomers, but as they are now known to be extra-terrestrial objects, they no longer fall within the scope of our science, and will not be further referred to here. A science of celestial meteorology, or the probable weather conditions existing in other worlds than ours, can scarcely be said to exist, though speculations have been often indulged in as to the habitability of the nearer planets. The phenomena of belts on the major planets Jupiter and Saturn have been likened to the trade-wind zones of our own earth, etc. With all such matters, notwithstanding its etymology (τὰ μετέωρα, things above), meteorology does not deal, leaving to astronomy whatever may be known or imagined as to the physical and climatic conditions of the other bodies of the universe; confining itself to the study of the physical state of our own atmosphere, its distribution and temperature; changes in these elements from day to day and throughout the year, their bearing on climate and habitability; and, lastly, the possibility of inferring future changes from present conditions.

CHAPTER II

THE BAROMETER—MERCURIAL BAROMETER—GLYCERINE BAROMETER—FORTIN'S BAROMETER — ADJUSTMENTS — SYPHON BAROMETER—FISHERY BAROMETER — ANEROID BAROMETER — SELF-RECORDING BAROMETERS — CORRECTIONS TO READING OF BAROMETER — WEATHER VARIATIONS WITH BAROMETER — OSCILLATIONS OF PRESSURE, DIURNAL AND ANNUAL — EXTREME RANGE—DOVE'S RULES—REGIONS OF HIGH AND LOW PRESSURE—PRESSURE AT VARIOUS ALTITUDES ABOVE THE SURFACE.

THERE is probably no instrument to which the progress of modern meteorology is due so much as the barometer, the measurer of the weight, or rather pressure, of the atmosphere. The name is derived from the two Greek words, *βαρὺς*, heavy, and *μέτρον*, a measure. It is an often-told tale that some Florentine workmen, finding that they were unable to raise the water in a pump to a greater height than 32 feet above its level in the well, came to Galileo to enquire the cause. The rise of water in a pump having been attributed to nature's abhorrence of a vacuum, he remarked upon this that it was evident that this abhorrence did not extend beyond 32 feet! Torricelli, one of his favourite pupils, some time after Galileo's death, considered that this water column was supported by the pressure of the external air upon its surface, this forcing the fluid up to a height varying with the pressure and the density of the matter raised. A heavier liquid than water he thought would rise to a less height. Taking a glass tube closed at one end, and filling it with mercury, whose density is thirteen and a half times as great as water at the same temperature, he inverted this, holding it upright, over a larger vessel partly filled with mercury also. The liquid in the tube fell somewhat, part of it passing into the vessel, and on measuring the height of the top of the liquid above the surface of the mercury in the vessel, he found this to be about 30 inches. Thus was formed the first *mercurial barometer*. The space above the top of the mercurial column, between this and the top of the tube, was empty, and is known as the Torricellian vacuum. It is a nearly perfect vacuum, containing only a trace of mercury vapour. The height of the mercurial column was found to vary somewhat from time to time at the same place, and very considerably, when the apparatus was moved from place to place.

Thus Pascal, the famous self-taught geometer, afterwards not less celebrated as a theologian, found that on the top of the Puy-de-Dôme, one of the extinct volcanoes in the Auvergne region of France, the height of the mercurial column above the level of the cistern was only about 25 inches as compared with 30 inches in the town of Clermont. Thus it was shown that the smaller amount of air over the instrument on the mountain supported a shorter column than in the valley below. The earliest form of mercurial barometer differs but little from those at present in use; the Accademia del Cimento employed a nearly closed cistern containing mercury into which dipped an upright glass tube graduated along its length and supported by the neck of the cistern. The most ordinary fluid for barometers is mercury, on account of its being much *denser* than any other known liquid, and *giving off but little vapour* at ordinary temperatures; but other liquids have been also used.

There is a glycerine barometer at the Geological Museum in Jermyn Street, London, and water barometers have also been occasionally employed, but though the great length of these instruments enables minute variations in atmospheric pressure to be more easily seen, yet their very length is itself a disadvantage, and the amount of vapour given off thereby producing a depression of the barometric column varying with temperature and other conditions, necessitates the use of troublesome corrections before the true pressure can be obtained. In addition, there is the very considerable effect of capillary "attraction." On the other hand, mercury is a liquid which may be easily obtained reasonably pure, and its rate of expansion for different temperatures is well known and very regular within the ordinary range employed. Of the various forms in use we propose to describe only one or two of the most ordinary.

The simplest kind of barometer, as already mentioned, consists of a glass tube supported in an upright position over a cistern nearly full of mercury, its lower end dipping into the latter. The barometer tube is filled nearly full with mercury, and is then heated till the fluid boils. Thus any air or moisture contained in the tube is expelled. It is thus completely filled with mercury, and inverted in the cistern. The atmospheric pressure at any moment is measured by the height of the top of the mercury column above the surface of the liquid in the cistern. A scale whose zero point is at the level of the latter surface, divided into inches and fractions of an inch (or into millimetres), affords the means of doing this. As, however, the mercury in the tube is supported by the pressure of the atmosphere, and the latter varies continuously, the length of the column must also vary accordingly; consequently the level of the mercury in the cistern must also change, for when the fluid rises in the tube its level must fall in the cistern, and *vice versâ*; thus the position of the surface in the latter must change, falling when the height in the tube increases, and rising when mercury flows from the tube into the cistern. Thus, to allow for this change of level, an arrangement, such as that adopted for the well-known Fortin form, must be adopted. This instrument is a cistern barometer, containing mercury as the fluid, with a scale whose lower end is a fixed ivory pencil. Before reading the instrument, in most cases the point will either be below the surface of the mercury in the cistern or else slightly above, but by means of a screw at the bottom of the cistern the latter may be raised or lowered till the point of the ivory pencil is in contact with the mercury surface, which is shown by the apparent contact of the point and its image reflected from the liquid metal.

Standard Barometer.
(Fortin's pattern.)

The reading of the scale at the top of the upper surface will then give the *apparent* barometric height. Another adjustment is necessary, however, before this reading can be ascertained. It will be noticed that the surface of the top of the mercury column in the tube is not flat but curved, slightly convex upwards, being highest in the centre. The reading of the scale *at the highest point* must be taken, the eye must be as nearly as possible on the same level, and most instruments are provided with a *vernier*, whereby the reading may be made with a greater degree of accuracy. In barometers in ordinary use in this country the scale is divided into inches, 10ths and 20ths of an inch. The vernier is a small movable scale divided into a number of equal divisions, such that a fixed number of these are equal in length to one *more* or one *less* than a number of divisions on the fixed scale. Very frequently, as we have stated, the scale of the barometer is divided into 20ths of an inch, and twenty-four of these divisions correspond to twenty-five spaces on the vernier, whereby $\frac{1}{20} \times \frac{1}{25} = \frac{1}{500}$ inch may be read off, or $\frac{1}{1000}$ inch by estimation. The bottom of the vernier being brought exactly on a level with the convex top of the mercury column, the reading is made. The line on the scale next below this point is noted, and this gives the nearest $\frac{1}{20}$ inch (·05), the smaller fractions being taken from the vernier. Thus suppose that the line on the main *scale* next below the bottom of the vernier is 29·550 inches, and that the next line above the 3 on the vernier coincides with one on the main scale, when the instrument is set each long line on the scale corresponds to ·1 inch, and the intermediate short lines ·05 inch, every long numbered line on the vernier gives the ·01 (100ths), and the short lines ·002 (2,000ths of an inch.) Then the reading is 29·550+·03+

·002 = 29,582 inches. The attached thermometer is to give the temperature at the time of the reading, for in reducing the reading of the barometer the correction for temperature is a very important one. This thermometer should be read *before* the barometer. Of other forms the best known are the "syphon" barometers, the "fishery" barometer, and "aneroid" barometers.

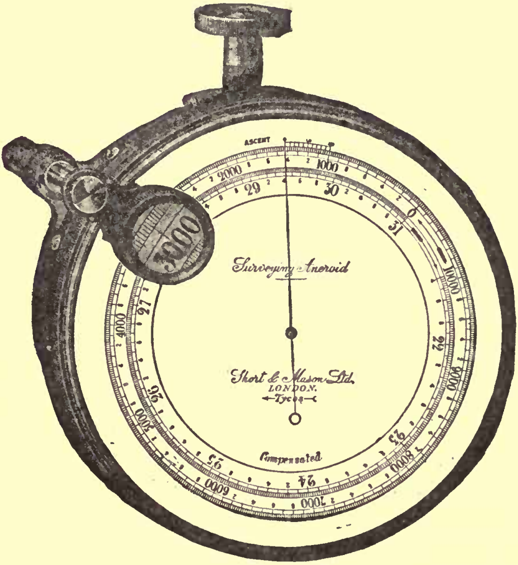
The syphon barometer, as its name indicates, has a tube bent up into a U-shaped form, a short open end about 6 to 8 inches long, and a longer closed end, the whole supported in a vertical position, the two ends upwards. There is no need, therefore, for a cistern in this form of the instrument, for when mercury is introduced into the open end it runs down and gradually rises in the other limb, the atmospheric pressure on the open end supporting a column in the closed part, whose height varies according to the variations in the former.

The distance between the levels of the mercury in the open and closed ends respectively gives the height of the barometer, and scales are provided to enable the necessary measurements to be made. If properly made with a correct scale and uniform tube, no correction for capillarity will be required for this instrument, the only corrections being those for temperature and altitude above (or depression below) mean sea-level. This form of instrument, however, is not so much in use in this country as on the

Continent. A thermometer is mounted to the same framework to give the temperature of the instrument at the time of reading.

The fishery barometer was designed by the late Admiral Fitzroy, some time Director of the Meteorological Office. It is a mercurial barometer fastened to a box-wood frame, the mercury column dipping into a box-wood cistern which has a flexible sheep-skin base and is provided with a lifting screw. There are two verniers, reading to hundredths of an inch, one being placed on each side of the tube, and a large attached thermometer. Many of these instruments are erected at exposed positions on the coasts, at coastguard stations for the "use of fishermen, sea-faring persons, and the public generally" (whence the name). The lettering on the instrument is the result of considerable experience, and is more accurate and reliable than that on the ordinary "weather glass." These instructions, from the name of their designer, are known as Admiral Fitzroy's rules.

A common and portable form of barometer is the well-known aneroid, usually made in the form of a watch or chronometer. In this instrument the pressure of the atmosphere is measured by means of its effect in altering the shape of a metallic box from whose interior the air has been partly removed, the upper surface of the box being corrugated to make it yield more easily to external pressure. At the centre of the top of the box there is a pillar connected with a powerful spring, to keep the box from collapsing. The top of the box rises or falls with the variations of pressure, and these movements are transferred by means of levers and springs to a hand which moves on a dial like a clock face. The instrument has to be graduated by comparison with a mercurial barometer ; it is very quick in indicating changes of pressure, and may be made small enough to go in the waistcoat pocket, and is thus very convenient for mountain observations, etc.



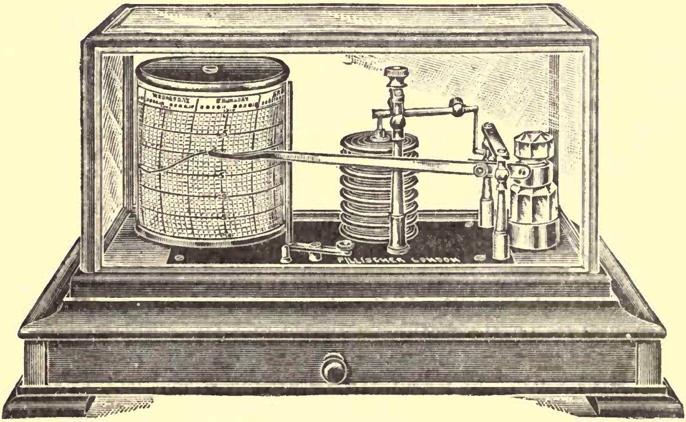
Aneroid.

It has the drawback of being affected by changes of temperature to an uncertain degree, each instrument acting differently in this respect, and, moreover, it is liable to gradual changes which necessitate its frequent comparison with a standard mercurial barometer, so that for exact scientific work there are serious objections to its use.

The *wheel barometer* consists of a mercurial syphon barometer, whose two branches have usually the same diameter. On the surface of the mercury in the open branch there floats a piece of metal or glass suspended by a thread, to the other end of which is fixed a pulley on which the thread is partly rolled. Another thread, rolled parallel to the first, supports a weight which balances the float. A needle moving on a dial is fixed on the axis of the pulley, and the float moving with the rise or fall of the mercury, the pulley turns and the needle with it, thus recording the variations of pressure. The instrument has the disadvantage resulting from the friction arising from this additional apparatus, and is consequently slow in indicating changes.

Self-recording mercurial and aneroid barometers or "barographs" are in use at large fixed public observatories, and some of the cheaper forms are used also by private observers.

They usually need comparison with standard mercurial barometers, and when this is regularly done their records, as giving the continuous variations of pressure for every moment, are of great value in detecting minute irregularities and variations of short period, which would otherwise escape notice. The photographic method in use at Kew and Greenwich consists in recording photographically the varying position of the top of a mercurial barometer. Sensitized paper



Barograph.

is wrapped round a cylinder, which is turned with uniform motion. Usually one complete revolution of the cylinder is performed in a day. Light from a lamp behind the barometer falls upon the paper, but is intercepted by the mercurial column to a greater or less degree, the line of division between the part acted upon by the light and the unaffected part varies according to the varying height of the column, every part of the cylinder, except that on which the spot of light falls, being covered with a case of blackened metal. Thus there is traced upon the paper a boundary curve whose ordinates (heights) are proportional to the movement of the barometer, and on developing the image the trace becomes visible to the eye.

The readings of every barometer, to bring the indications of different instruments into harmony, need various corrections before they can be applied for comparison, or other purposes. They are usually given as five (or six) in number.

I. Correction for Index Error.
(II. „ „ Capacity).
III. „ „ Capillarity.
IV. „ „ Temperature.
V. „ „ Altitude above Sea-level.
VI. „ to reduce to mean latitude 45°.

Of these the first three corrections vary for different instruments, and are often previously obtained by comparison with standard instruments (II., does not apply to Fortin's barometer), whilst the corrections IV. and V. are conveniently applied by means of tables, since they are the same for all instruments under similar conditions.

The *Correction for Index Error* is the amount to be applied to the readings owing to the fact that the scale (inches or millimetres, etc.) is not quite accurate, so that a given reading, say 29 inches on the standard barometer, corresponds to a somewhat lower or higher reading on the instrument under comparison.

It is stated that some instruments have been found to read half an inch too high, others as much too low (Scott). Others again, which are correct in one part of the scale, are found to be several tenths of an inch wrong in other parts. The usual practice at Kew is to test them at every half inch from 27·5 to 31 inches (of mercury), and the corrections thus found are registered in a table to be used with that particular instrument. Any barometer whose index error is greater than 0·010 inch *is to be rejected* (Kew, 1875).

The *Correction for Capacity.*—In barometers with closed cistern there is a certain height for the mercury at which the column is correctly measured by the scale. Below this, since when the mercury sinks in the tube it rises in the cistern, the height read off must be too great; and, conversely, the level in the cistern falling as the mercury rises in the tube, readings will be too low when this is the case. When the ratio between the capacity of the tube and the cistern is known we may allow for this as follows: Suppose the capacity of the tube to that of the cistern to be $\frac{1}{100}$, and we know the height at which the reading of the scale is correct, *this* is called the "neutral point." Then by adding a $\frac{1}{100}$th part of the difference between the height read off and that of the neutral point, we get the true reading when the column is higher whilst we subtract the difference when the column is lower. It will be remembered that Fortin's barometer having a movable cistern, the zero of the scale is always at the level of its surface, and so no such correction is wanted for instruments of that pattern.

The *Correction for Capillarity* arises from the fact that there is what is called a capillary repulsion between mercury and glass. The surface of the former in a glass vessel is never horizontal, but is lower at the edges than at the centre, and, moreover, this depression is greater in narrow tubes than in broad ones, being nearly inversely proportional to the diameter of these latter. It has also been found to be greater in tubes in which the mercury has not been boiled than in those where it has been so treated.

But the more important of the corrections to be applied are those for temperature and altitude, to be next described.

The *Correction for Temperature, or Reduction to Freezing Point* (32° F. or 0° C.).—The attached thermometer gives the temperature at the time of observation. Since all bodies are affected by change of temperature, usually expanding with its increase and contracting with decrease, the length both of the mercury column and of the scale itself will vary with variations in temperature, apart from the rise or fall of the mercury due to pressure changes. Mercury being a liquid, is more expansible by heat than either glass or the scale, and consequently the level of the barometer will rise with any rise in temperature and fall with a fall of temperature, even though the air pressure remain constant. All readings of the instrument are accordingly reduced to the temperature of the freezing point (32° F.), and tables are given which enable the correction to be applied to the observed length at other temperatures to reduce them to the value they would have at that standard temperature, the temperature of the instrument at the time of observation being given, of course, by the attached thermometer.

Correction for Reduction to Sea-level.—The height of the barometric column, being a measure of the pressure of the atmosphere, is greater or less, according as the latter varies, and so it is evident that if we ascend above the level of the surface of the ground, there being less air as we go up, the pressure will be less, and consequently the barometer will fall, whilst, conversely, if we go down into a mine, the air pressure will be greater than that at the surface. For moderate elevations above the surface the barometer falls about $\frac{1}{10}$ of an inch for each 100 feet of altitude, but this amount varies not only in different places, but also with variations of temperature. We may determine the height of a mountain or other elevated station by readings taken at the sea-level and the station respectively, and the barometric determination of heights depends upon this comparison of readings. Tables of more or less exactness are given to enable the correction to sea-level to be made, and for the British Isles the mean sea-level at Liverpool (Ordnance Survey) or "high water at London Bridge," is taken as the zero of altitude.

The last "correction," *Reduction to Mean Gravity at Latitude* 45°.—To reduce the readings of the barometer to a standard of comparison available all over the globe, it has been proposed to take as the standard the value of *g*, the acceleration due to gravity, at latitude 45°, its value varying slightly at different latitudes from 32·086 in foot second units (or 977·99 C.G.S. units at the Equator to 983·21 at the Pole) at the Equator to 32·258 at the Pole, and multiply the barometric readings by the proper factor, ratio of gravity at the station to that at latitude 45°. For latitude 50° this is nearly equivalent to a correction (addition) of +·014 inches to the barometer at 30 inches, and about +·013 inches (barometer 29 inches). This correction, however, is not often applied, and, of course, is only for mercurial barometers and not for aneroids. In practice the corrections for index error, capacity (if required), and capillarity are contained in *one*, the "Kew correction," when the instrument has been tested at that institution, and after this is made, the corrections for temperature and altitude are next applied. As an example of the way in which these corrections are made, we may take the following, given by Mr Scott:—

Uncorrected reading . .	29·946 in.	Attached thermometer 68° F. Altitude of cistern, 105 feet above sea-level.
Kew correction . . .	+·014	(Air temperature), dry-bulb thermometer, 50° F.
	29·960	
(Deduct) Temperature correction for 68°	−·106	
	29·854 =	(Reading at 32° F.).
Altitude of 105 feet at temperature 50° and approximate pressure 30 inches	+·116	
	29·970	(Reading corrected and reduced to 32° F. and M.S.L.).

Note.—In applying the correction for altitude we must know the air temperature at the time, for the difference of pressure between the sea-level and the place of observation is for the *height* of the vertical column between the two positions, and the weight of this column varies with its temperature, being less for hotter air than for colder.

The old and familiar name of "weather glass" for this instrument has already been alluded to as well as the notation engraved on the scales of many barometers.

This usually appears in accordance with the idea of high barometer for fine weather and low barometer for bad, something as follows:—

31 inches = very dry.
30·5 " = set fair.
30 " = fair.
29·5 " = change.
29 inches = rain.
28·5 " = much rain.
28 " = stormy.

Apart from the fact that these terms are of very limited application, being only roughly true for places at mean sea-level and under normal conditions, it often happens that rain falls with a high and rising barometer, and we frequently get fine weather when the latter is low, so that this notation is practically worthless. The fishery or Fitzroy barometers, instead of the above misleading and imperfect notation, have instructions engraved on their scales applicable to the usual course of the weather in these islands.

In a general way the barometer in these latitudes varies most irregularly, but in tropical regions, apart from occasional storms, there is a regular daily rise and fall. It generally rises from a *minimum* at 4 A.M. to 10 A.M., when it attains its *first maximum*, then falling again to 4 P.M. *second minimum*, rising again to a *second maximum* at 10 P.M. So regular is this oscillation that it is sometimes stated that the hour of day can be ascertained by the height of the barometer. Any irregularity in this daily oscillation is an unfailing sign of a storm. The morning maximum and the afternoon minimum (10 A.M. and 4 P.M.) differ more from the mean than the other oscillations. At Calcutta the *diurnal range*, or difference between the extreme values, is about 0·12 inch. This range is very much smaller at stations in higher latitudes, but has been detected everywhere *where the alternation of day and night exists* (Herschel), and is evidently due (partly) to the action of the sun, "though the causes are not yet thoroughly worked out." There is a probability, however, that the moon, too, has an action here, and that, like the ocean tides, both sun and moon are instrumental in producing an "atmospheric tide." On this point letters by Mr Dines and Mr Langdon in Symons' *Meteorological Magazine*, April 1910, may be consulted, under the heading of "Atmospheric Tides."

"It is fairly certain that the natural period of oscillation of the atmosphere as a whole is about twelve hours. Thus the tide-producing power of the sun must inevitably produce some such tide as we see in the double daily barometric oscillation."—DINES.

It appears, from examination of various series of long-continued observations, that there is also an annual period as well as a daily one, but this variation is small for our islands, though for continental regions it is sufficiently well marked. The characteristic high barometer over central Siberia during the winter, as compared with the much lower readings during the summer in that country, are well known. The same thing is generally true to a less degree of the mean pressure over North America during the same seasons.

The extreme range at sea-level in our latitudes may be roughly taken as about 3 inches, from 28·0 to 31·0 inches of mercury; its mean height being rather under 30 inches, "one atmosphere" being conveniently expressed as the pressure equal to this value. More exactly, the value of the standard pressure is defined as such that it will support a column of mercury 76 cm. high, at latitude 45° and at the sea-level, the temperature of the mercury being 0° C. (32° F.) (Watson's "Physics"). For our latitude (51° N.) the standard pressure usually adopted is 29·905 inches of mercury, under which pressure the boiling-point of water is 212° on the Fahrenheit scale, which is slightly smaller than the value 76 cm. for the latitude of Paris, corresponding to 29·922 inches.

It is not often that readings of the barometer under 28·5 inches or over 30·5 are recorded at stations on the sea-level. Occasionally, during storms, readings under 28 inches are taken, as at Ochtertyre in Scotland, during the great storm of 26th January 1884, when a reading of 27·332 inches was recorded, and throughout the day readings under 28 inches were taken in the north of Ireland and Scotland. As examples of high barometric readings, I have myself on several occasions observed the barometer standing slightly over 31·0 inches at Markree, at the end of January 1902. Much higher readings have been observed during the long continuance of the winter anticyclone over Siberia, 31·62 inches having been recorded at Barnaoul in December 1877.

Professor Dove's practical rules on the relation of barometric changes and wind direction may be thus condensed (for Europe):—

The barometer falls with east, south-east and south-west winds. It rises with west, north-west and north winds. It ceases to fall with a south-west wind and begins to rise; with a north-east wind it ceases to rise and begins to fall. These rules were originally given for the whole Northern Hemisphere, but it has been shown that for Asia and the extreme northern regions of America and Greenland, they are not correct (Scott). Similar rules for the Southern Hemisphere by interchanging of north and south, were propounded by the same authority.

Dr Schreiber of Leipzig has, however, shown that these relations are not necessary, that wind direction and barometric pressure are probably more complex functions of the general weather conditions. The warmest currents are usually the dampest, and the relative humidity and probability of rain are *roughly inversely* as barometric pressure, but have also a minor relation to wind direction. Thus we have the usual relation between a higher rising barometer and fine weather and falling barometer with rain and wind; the fall being greater for high winds than for heavy rains. Most generally a rise of the barometer is accompanied by a fall of the thermometer and *vice versâ*, but whenever a simultaneous rise of both instruments occurs it may be taken as "a sure sign of steady fine weather." The contrast between the weather conditions implied by the slow or rapid movements of the barometer is well expressed in the following couplet:—

> "Long foretold, long last;
> Short notice, soon past."

A rapid rise or alternate rising and falling indicates unsettled weather conditions, whilst a gradual rise foretells fine weather, and a gradual fall during fine weather is a promise of a spell of continued bad weather. With regard to the amount of rise or fall of the barometer in a given time it may safely be said that a fall of $\frac{1}{10}$ inch in an hour, or $\frac{3}{10}$ inch within three or four hours, is a sure indication of a coming storm (Chambers).

Professor Mohn in his "Meteorologie" summarises the general reasons for a high or low barometer (apart from storm and violent changes) as follows. The barometer is high when the air is very cold, the lower strata being more dense than when it is warm, and more contracted, thus causing the upper strata to sink down and bring a greater *mass* of air, thus increasing the pressure at the base (recorded by the barometer). When the air is dry it is *denser* than if partly composed of moisture (the vapour of water having only ·62 the density of air at the same temperature and pressure), and thus the barometer is high.

Whenever an upper current sets in towards a given area, compressing the lower strata, this also causes a high barometric pressure. On the other hand, the barometer is low when the lower strata are heated, the isobaric surfaces (surfaces of equal pressure) are elevated, and a barometric slope causing motion results, so that the mass of air pressing on the lower regions is reduced. When the air is damp its density is reduced, and the more so the greater the amount of this moisture, since, as we have already stated, water vapour at the same temperature and pressure has only $\frac{5}{8}$ths the density of dry air. Whenever the air has an upward tendency, its pressure is lessened, so the barometer reads lower.

The presence of deep snow is another favourable condition for a high barometer, for this tends to prevent changes (rises) of temperature by interposing a non-conducting layer between the air and the ground.

We accordingly find that the regions of highest barometrical readings are situated in the interior of continents and in high latitudes at the time when the temperature is lowest, as, for instance, in Eastern Siberia during the winter, where a constant anticyclone prevails for many months. The much greater proportion of water to land in the Southern than in the Northern Hemisphere, whilst it tends on the whole to *raise* slightly the mean temperature of places in southern latitudes over those of corresponding regions north of the

Equator, similarly tends to lower the pressure over the former. Between latitude 40° S. and the South Pole there is little land beyond a few scattered islands, with the exception of the supposed Antarctic continent, which in any case is probably much smaller than the land round the North Pole. Thus the atmosphere over a large portion of the Southern Hemisphere is more heated than at equal latitudes of the northern half of the globe, so that the "isobaric surfaces" are raised and the differences of pressure between the Equator and higher latitudes diminished. This difference of pressure being the force tending to produce a flow from the Equator towards the polar regions, a smaller mass will ascend, and consequently the pressure (due to the weight of the superincumbent atmosphere) will be correspondingly less. The presence of any considerable mass of land near the South Pole must act as a "centre of indraught" for the upper currents from the warmer water surfaces around it, thus tending to still further reduce the pressure. To this defect of pressure is also attributed the exceptional force and frequency of the "brave westerly winds" which blow so persistently over the Southern Ocean.

[*Note.*—The variations of barometric pressure at different heights above the sea-level have been determined, and a table prepared by Dr Sprung gives the annual mean pressures, their mean values for January and July, and also for altitudes of 2,000 and 4,000 metres (6,700 feet and 13,000 feet), above the surface for 5° intensity of latitude from 80° N. to 70° S. From this table we find a *minimum annual* mean of 758·2 mm. at latitude 65° N., increasing thence to a maximum 762·4 mm. at 35° N., again decreasing to 757·9 mm. at latitude 10° N. From this to southern latitudes the mean annual pressure increases to 763·5 mm. at latitude 30° S., falling off again at higher latitudes (738·0 at latitude 70° S., the most extreme southern latitude given). At an altitude of 2,000 metres we have for latitude 80° N. 582·0 mm., increasing at first somewhat more rapidly to 600·9 mm. (latitude 30° N.), then more slowly, till in latitude 20° S. the maximum 602·7 is reached, after which there is a fall, at first slow, then more rapid, to 569·9 in latitude 70° S. The pressures at altitude 4,000 metres increase from 445·2 (latitude 80° N.) to 471·1 (latitude 10° to 20° S.), and then decrease to 437·2 at latitude 70° S. Thus for the Northern Hemisphere from this table we get a maximum pressure at latitude 30° N., a slight minimum at the Equator, and a more pronounced minimum at latitude 65° N., with a slight increase northwards, onwards towards the Pole. At elevations 2,000 metres the maximum pressure is nearer the Equator, and the same is the case with the observations for 4,000 metres altitude, there being only one minimum for each towards the polar regions, no increase of pressure in the highest latitudes being evidently such as the observations on the surface indicate. Sprung's numbers are given on the metric *units*; they may be reduced to British statute feet, and inches of pressure by remembering that 39·37 inches = 1 metre.]

CHAPTER III

THE THERMOMETER: SCALES, FAHRENHEIT, CENTIGRADE, RÉAUMUR, DE L'ISLE—THE HYPSOMETER—"WET AND DRY BULB" HYGROMETERS—DE SAUSSURE'S HAIR HYGROMETER—MAXIMUM AND MINIMUM THERMOMETERS — SELF-RECORDING THERMOMETERS (THERMOGRAPHS)—THE STEVENSON SCREEN—GLAISHER SCREEN—BLACK BULB THERMOMETERS—RANGES IN TEMPERATURE.

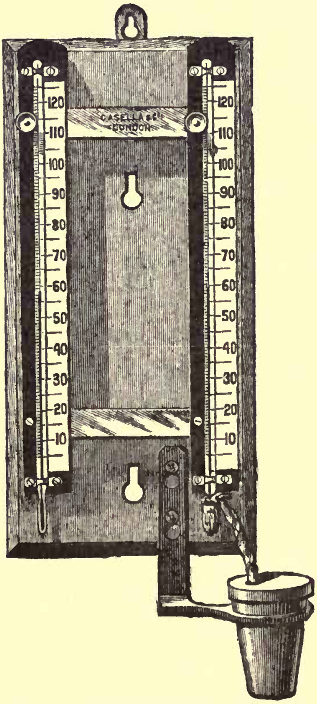
THE thermometer seems to have first made its appearance about the end of the sixteenth century, and its invention has often been attributed to Galileo, though there is reason to believe that some kind of instrument for measuring temperatures was in use before his time. Galileo, however, used at Padua a glass bulb with a narrow open tube attached to it. This bulb was heated, and the open end of the tube placed under water in a vessel. The water rose to a certain extent in the tube, and as the air in the bulb cooled it rose still further, falling again when the bulb was warmed, exactly as the modern differential thermometer. About 1630 a French physician suggested inverting the Galilean thermometer, nearly filling it with a liquid, and observing the rise and fall of the liquid with changes of temperature.

The "Florentine thermometer," invented by pupils of Galileo, consisted of a bulb with a fine tube above, and the fluid employed was alcohol; the tube divided arbitrarily by means of small glass particles attached to its side, the zero being at about the point to which the liquid fell in a freezing mixture of salt and water. The substitution of mercury for alcohol, first suggested by Halley, has such obvious advantages that the former is now always used for exact observations, except for such temperatures as are occasionally met with in very cold countries, where mercury freezes in the winter. Mercury is a substance which can be obtained with considerable purity, and is liquid throughout the *ordinary* range of meteorological observations. In addition it has a low specific heat and great conductivity, so that it is quickly affected by changes of temperature, and soon indicates these. The first use of the freezing- and boiling-points of water as fixed temperatures is variously attributed to Newton and Fahrenheit, the latter of whom also divided the interval between these temperatures into 180 parts or degrees. Finding that the temperature of a mixture of snow and salt was 32 of these degrees below the freezing-point of water, he called this latter the zero temperature (perhaps supposing no lower temperature to be possible), and the freezing-point being thus 32, the boiling-point became 212. This scale is in almost universal use in this country, though originally "made in Germany," and has the advantage that in expressing observed temperatures it is very rarely necessary to use the negative sign (–) for temperatures below zero, whilst the small size of its degrees is also useful.

The scale, however, which is in general use throughout Europe is that known as the Centigrade. In this, the interval between the freezing- and boiling-points of water is divided into 100 degrees, the freezing-point being 0° (or zero) and the boiling-point 100°. It is commonly stated that the invention of this scale was due to Celsius, but it appears that the credit should be given to Linnæus (Scott, "Meteorology," p. 19). The former called the boiling-point 0°, and the freezing-point 100°, the degrees running downwards, whilst the suggestion of Linnæus that the freezing-point should be called 0°, and the boiling-point 100° agrees with the present universal practice. A third scale, proposed by Réaumur, is still sometimes used in Germany and Russia. On this the freezing-point is 0°, but the boiling-point is 80°, the degrees being thus larger than on the centigrade scale. A fourth system, proposed by Dr De L'Isle in 1733, divides the interval between the freezing- and boiling-points of water into 150 degrees (but this is nowhere in use at present so far as we are aware), reckoning backwards from the boiling-point. Rules are sometimes given whereby temperatures on one scale may be converted into corresponding readings on any or all of the others, but being a matter of pure arithmetic and of very little general utility, we need not waste space to do that which any reader can do for himself. It is to be hoped that in a few years' time all save one scale will be mere matters of antiquarian interest. At present, however, it is necessary for the English reader to acquaint himself with the Fahrenheit and Centigrade scales, the former because it is in general use in this country, the latter because almost all continental writers use it, and it is even gaining ground here also, being generally adopted by chemists and physicists, if not by meteorologists.

Under ordinary conditions we may look upon the freezing-point as a constant temperature, since it is only slightly affected by variations in atmospheric pressure, being only lowered 0·0075° C. = 0·0135° F. by one "atmosphere" increase of pressure, and for the ordinary variations the depression or elevation is smaller than the probable error of the thermometer. On the other hand, the boiling-point of water is greatly affected by variations in the intensity of the superincumbent atmospheric pressure, and a difference of 1 inch above or below the standard (usually taken at 30 inches, or more exactly 29·905 inches of mercury) raises or lowers the boiling-point by 1·7° F. (on the metric system an increase of 27 mm. in pressure corresponds to 1° C. rise in boiling-point, and conversely). On this variation in the boiling-point depends the *hypsometer*, an instrument for the measurement of height (Greek ὕψος, height; μέτρον, a measure): which is nothing but a boiling-point thermometer with a large scale whereby the temperature at which water boils on a mountain may be easily ascertained by performing the experiment. Then from the tables the barometric pressure corresponding to the ascertained boiling-point is known, and, with less exactness, the height of the mountain may be inferred. As, however, we know that the barometric pressure at any point on the surface varies within a range of 2 or 3 inches, the results of hypsometrical observation are liable to considerable uncertainty.

The simplest form of hygrometer, or instrument for measuring the amount of vapour present in the atmosphere at any given time, consists of the "wet and dry bulb" arrangement. This is merely two similar thermometers mounted side by side on a frame (often inside a Stevenson's or other screen), the bulb of one being wrapped in muslin or other soft material, whilst the other thermometer has its bulb uncovered. The muslin is tied round the bulb by means of a few threads of worsted or cotton, the other ends of which dip into a small vessel of water, which is kept fairly full. The two thermometers being compared, it will be found that the "wet bulb" instrument will in general read somewhat lower than the other. So long as the air is not saturated with moisture, some of the water carried up by the threads to the muslin will be continually evaporating, and this evaporation causing an absorption of "latent heat," the temperature of the instrument will be lowered thereby. When the air is saturated at any given temperature no more moisture can evaporate, and so the wet bulb and dry bulb thermometers will give the same reading. Thus we may see that the difference between these two will be a measure of the amount of vapour present in the air at any given time. The theory of this instrument, sometimes called the "psychrometer" (ψυχρός, cold; μέτρον, measure), has been investigated by Apjohn, August, and others, and tables have been formed by Glaisher, as the



Wet and Dry Bulb Hygrometer.

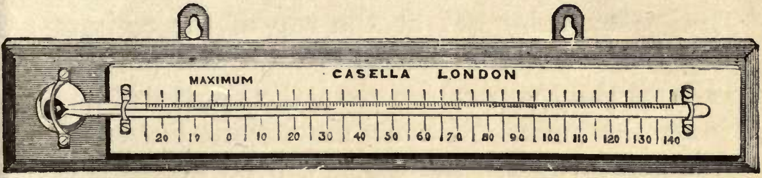
result of experiments carried on at Greenwich and elsewhere, whereby from the observed readings of the dry and wet bulb thermometers the amount and pressure of the aqueous vapour of the atmosphere may be obtained, approximately at least for our latitudes.

Regnault's and De Saussure's hygrometers are but little used in this country, though the latter instrument was recommended by the Vienna Congress of Meteorologists. This, the "Hair Hygrometer," consists essentially of a human hair, which is fixed at one end and stretched by a small weight at the other, the cord of connection passing over a block to which is attached a pointer, which moves over a graduated arc. The hair stretches as it grows damp, and contracts as it dries, the pointer at the same time moving either forwards or backwards, its position varying with the length of the hair. Other hygroscopic substances, such as seaweed, which grows damp in wet weather and dries when the weather is fine, wild oats, whose life-like movements under the influence of moisture are well known, catgut, etc., are sometimes employed, but rather as "hygroscopes" (or *indicators* of moisture) than hygrometers (*measurers*).

Whilst the reading of the thermometer gives the temperature at the moment of observation, it is for many purposes desirable to know not only what the temperature is now, but what has been the highest and the lowest temperature during the interval since the last observation, the greatest heat of day and the lowest temperature at night, etc. There are many varieties of instruments whereby this information may be obtained, but of course only a few of the more commonly used forms can be here mentioned. Instruments for recording the highest temperature during a given interval (*e.g.*, the course of a day) are called *maximum* thermometers, those giving the lowest temperature are consequently known as *minimum* thermometers.

Of maximum thermometers perhaps the most generally used form is the Phillips', invented by the well-known geologist, though that of Negretti and Zambra is as good and quite as often recommended. This is a mercurial thermometer having a tube whose bore is narrowed close to the bulb. The mercury on expanding rises past this obstruction, but when the temperature falls again, the liquid cannot flow back again with ease. Thus if the thermometer be set on any day, say in the morning, and examined after the temperature has risen and fallen again, the column of mercury in the tube above the constriction will represent the amount of liquid forced past it when the temperature was highest, and the end furthest from the bend or constriction will indicate the maximum temperature. Phillips' thermometer has a small air bubble separating a detached portion of mercury from the main column.

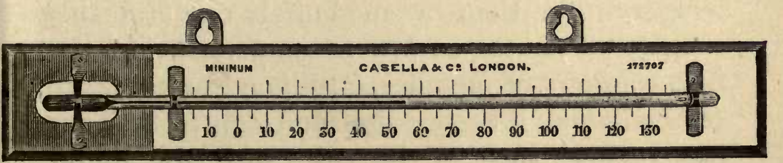
When the latter expands, it pushes the bubble and short column before it, but when the temperature falls, though the main column contracts and leaves the air bubble behind, the detached column also contracting, but to a minute degree,



Maximum Thermometer.

its end furthest from the bulb indicates the highest temperature since the last reading. To set the instrument it is inclined gently, bulb downwards, when the air bubble becomes contracted to its smallest dimensions, the detached column compressing it, and coming close to the main portion.

The *minimum thermometer* in most common use is that known as Rutherford's. In this instrument the liquid is coloured spirit (usually



Minimum Thermometer.

alcohol) having a metal index. This index is allowed to run to the end of the column by inclining the thermometer with its bulb slightly upwards. At the same time any detached portion of the spirit is brought back to the main column by gently warming, or sometimes this may be done by swinging the instrument to and fro, *bulb downwards.* When this is done, the index being set at the top of the column, the thermometer is left in a horizontal position. If now the temperature rises, the spirit will flow past the index without moving it, but if the temperature falls, the index will be drawn back with the contracting fluid, for the spirit will not easily admit of its surface being broken by the index getting outside, "capillary attraction" keeping the index with its upper end just below the top of the liquid column. Thus the top of the index will mark the lowest temperature, since it recedes with a fall, but remains stationary with a rise of temperature. Care must be taken that the index is within the spirit, and that no detached column remains in the upper end of the tube.

Though a spirit thermometer can record lower temperatures than a mercurial one (in this country of course so low a temperature as the freezing-point of mercury, −40° is never naturally reached), yet its expansion and contraction are less regular than is the case with the liquid metal, errors are frequent from the presence of air in the tube, from evaporation of part of the liquid column, etc., so that it needs frequent comparison with a standard mercurial thermometer, and even then its readings are often not very reliable.

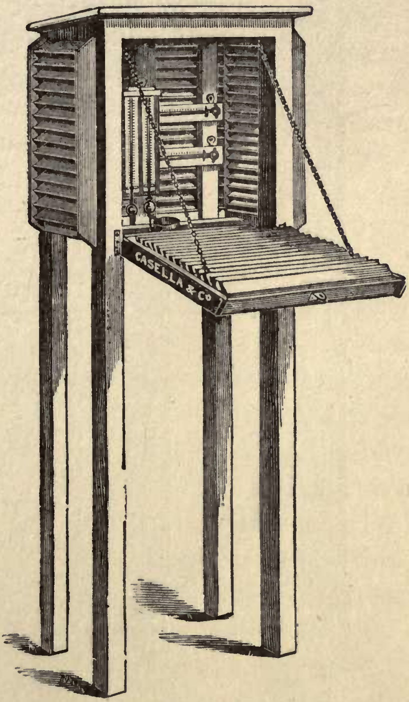
Self-recording thermometers are in use in various large observatories. A common method is to obtain a continuous automatic record by means of photography, in a manner similar to that adopted for the barometer. A sheet of sensitised paper is mounted on a vertical cylinder placed behind an upright thermometer, and is shielded from light by a blackened metallic cover, with the exception of a narrow strip just behind the position of the mercury. A beam of light from a lamp is thrown upon the apparatus, being stopped by the mercury in the tube; so that it only falls on the part of the paper above the liquid column. The cylinder revolving slowly (usually once in twenty-four hours, or sometimes a shorter interval), if the temperature remain the same, the boundary between the unaffected and blackened parts of the paper will be horizontal; if the temperature change, which it will do continuously, there will be seen a wavy line of separation, and thus the position of this will be a measure of the temperature at each moment.

The photographic thermograph affords another method of obtaining a continuous record. Here there is a bubble of air on the top of the mercurial column which moves up and down with the temperature. A lamp is placed in front of the instrument and a photograph of the position of the air bubble is taken on sensitised paper, which is rolled on a drum revolving uniformly.

For meteorological purposes various forms of screens, of which Glaisher's and Stevenson's are the most generally used, are adopted by different observers.

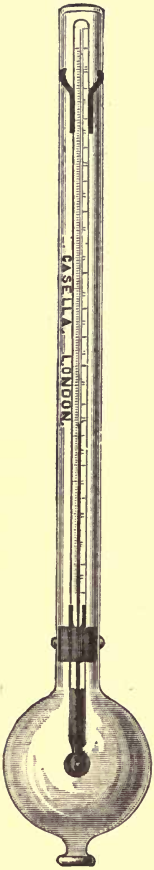
Whilst, on the one hand, it is necessary to obtain free exposure to the air, on the other hand, for instruments intended to give the air temperature, care must be taken to guard against direct radiation from the sun or neighbouring hot bodies, whereby the temperature of the thermometer may be unduly raised, whilst we must also see that it may not be lowered by radiation to colder bodies. As far as possible, the ordinary wet and dry bulb, as well as the maximum and minimum thermometers, must be surrounded by freely circulating air and be not too near other objects.

The Stevenson screen is made of wood, "double louvred," the louvres sloping in opposite directions, so that the air may freely circulate, but direct radiation, rain and snow are unable to enter. It is erected on four legs, each about 4 feet high, and should stand on open ground or over grass, and not be within 10 feet of any wall or other building if possible, nor near trees. Its dimensions are usually about 2 feet (length), 14 inches (breadth), and 18 inches (height). Inside it are placed the dry and wet bulb instruments, as well as the maximum and minimum thermometers, the two former being hung vertically side by side, the two latter suspended horizontally, one over the other. Below and slightly to one side of the wet bulb instrument is placed the vessel of water (cup or small glass), into which the ends of the strands tied round the muslin surrounding the thermometer bulb, dip.



Stevenson Screen.

In the Glaisher pattern there is a vertical board on which the thermometers hang, their bulbs being freely exposed to the air. This is attached to a sloping screen supported by a tripod. As the direction of the sun's rays changes during the day, the whole structure requires shifting once or twice daily, whilst in time of rain with northerly wind the instruments cannot be kept dry, as on that side they are merely sheltered on top and on one side. Thus it is in some respects less convenient than the Stevenson form of screen, whose double louvres prevent the entrance of any rain or snow. Special forms of instrument, such as the black bulb thermometer, which is a maximum thermometer of a particular kind, are used for measuring the intensity of radiation, its readings always being much higher than those of the other instruments. To the late Sir John Herschel, the well-known astronomer, is due the suggestion of its construction. It consists of a mercurial maximum thermometer, whose bulb and lower part of the stem are coated with lamp black. This apparatus is enclosed in a larger glass tube, one end of which is blown out into a large bulb, and the thermometer bulb rests in the centre of this. This cover has been previously exhausted of air as far as possible, by means of an air pump or otherwise, and is a partial vacuum. The whole instrument,



Solar Radiation
Black Bulb
Thermometer.

Grass
Minimum
Thermometer.

cover and all, is hung horizontally on a wooden structure at about the same height above the ground as that at which the other thermometers are placed (*i.e.*, about 4 feet) in the open air, and at a distance from walls of buildings, trees, or other obstructions. The bulb is exposed to the full rays of the sun, and protrudes usually some slight distance beyond the supports; it is usually directed south or southeastwards.

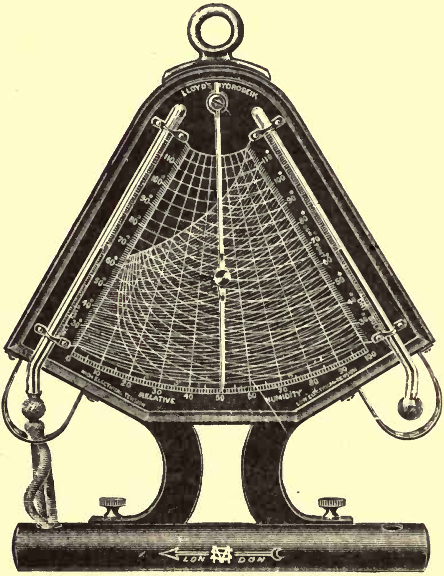
As a rough rule for measuring the maximum radiation from the sun, it is suggested to take the difference between the maximum reading given by this instrument and the maximum as given by the ordinary maximum thermometer in the screen, but it is not very easy to attach a meaning to the number thus obtained, which will, moreover, differ with different thermometers, according to differences in "the coating of the bulb, in the glass of the outer jacket, or finally, in the perfection of the vacuum" (Scott). The reading of the black bulb thermometer giving, perhaps, the highest temperature in the sun at any moment during the day without reference to its duration, can afford but an imperfect idea of the *amount* of solar radiation, so that we may regard this instrument rather as a curiosity than as of scientific value. Its high readings, sometimes even in winter, may excite our admiration, but, just as the phenomenally low temperatures occasionally recorded by grass minimum spirit thermometers, they are practically meaningless.

The daily range of temperature is least in winter, usually not exceeding about 5° or so, and greatest in summer, when it amounts (in this country) to about 15° or 16°, its value for spring and autumn being intermediate between those for summer and winter. Though the sun's altitude and the total amount of sunlight received are greatest on 21st June and least on 21st December, the hottest and coldest times of the year follow about one month after these dates. In accordance with the old proverb, "As the days begin to lengthen, so the cold begins to strengthen," it is when the days are getting sensibly longer, about the end of January or the beginning of February, that we experience the coldest weather in this country. Similarly it is in August that the *highest* temperatures are experienced, though the day is considerably shorter than during June. The coldest time of day is usually just before sunrise, and the hottest time about 2 P.M. The general and fairly evident explanation of all these phenomena is essentially the same. During the day heat is being received in increasing amount from sunrise to noon, after which a smaller quantity comes till sunset. All the while heat is being radiated *away* from the earth, but at a slightly less rapid rate, and thus during the morning the temperature increases even after the amount of heat received begins to diminish. Thus the hottest time of the day is *after* noon. During the night no heat is received from the sun, and so the temperature continually falls, radiation going on all the while till sunrise. In a similar manner the amount of heat received each day from the sun during spring continually increases up to 21st June, but the amount radiated away, though greater as time goes on, does not quite keep pace with the increased amount received. Thus the temperature continues to increase even after the maximum daily amount of heat has been received, until at about the end of July the amount radiated equals that received daily, and the temperature is a maximum. After this, the daily amount received continuing to diminish, the radiation by night exceeds the daily receipt, and so the temperature falls.

The mean daily temperature in this country will not differ much from the mean of the temperatures at 8 A.M. and 8 P.M., or 9 A.M. and 9 P.M., or if three observations are taken, the mean of the 9 A.M., 3 P.M., and 9 P.M. temperatures will give a very close approximation to the truth.

The mean of the maximum and minimum thermometers will not usually give quite so accurate a result, the maximum day temperature being generally slightly more above the mean than the minimum is below, so that the mean of the readings of the two instruments will be somewhat higher than the true mean temperature.

In instruments even of the best class occasional changes of zero, sometimes as much as 1° F., take place, necessitating examination of thermometers, and though of recent years great improvement in the construction of standard thermometers has been attained, it must be confessed that few instruments can be trusted within 0·2° or so, and this accuracy is perhaps more than is to be usually expected.



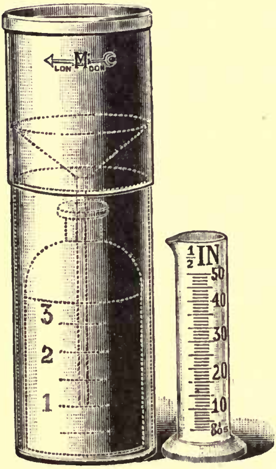
The Hygrodeik.

CHAPTER IV

RAIN GAUGES—SUNSHINE RECORDERS—WIND INSTRUMENTS—ANEMOMETERS—DISTRIBUTION OF RAINFALL.

THE measurement of the rainfall of any district is a matter in which perhaps more interest is taken than almost any other branch of meteorological science, and accordingly we find a very large number of stations throughout the British Islands where a rain gauge is installed and regular observations are taken daily, and reported to a central authority. The British Rainfall Organisation, founded by the late G. J. Symons, and now under the directorship of Dr H. R. Mill, publishes an annual volume, *British Rainfall*, giving the results of observations from more than three thousand five hundred stations in our islands, illustrated by maps and diagrams, with articles upon various branches of rainfall work, whilst Symons' *Meteorological Magazine*, a monthly magazine under the same editorship, contains records of rainfall and temperature at a number of stations each month, articles on meteorological topics, remarkable storms, a climatological table for the British Empire, and occasional contributions on other kindred subjects, as well as letters on remarkable meteorological phenomena, or points of interest to meteorologists generally.

There are many forms of rain gauge in use, from a simple upper funnel dipping into a glass bottle, to the most elaborate automatic self-recording gauge, or "pluviometer," as it is called. The commonest form, and one giving quite satisfactory results, is merely an improvement of Howard's rain gauge, so named from the eminent meteorologist whose careful study of cloud phenomena led him to a classification and nomenclature for these, now universally adopted. A copper funnel, whose upper diameter is 5 inches, dips at its lower end into a glass vessel—a wine bottle or jar with a neck will serve very well for this purpose. Sometimes the funnel and bottle are enclosed within a cylindrical copper vessel, on whose bottom the bottle receiving the rain rests, and to whose top the rim of the funnel is fitted. At the top, and forming part of the funnel, is a "vertical rim" about 6 inches in depth, and the inner surface of this rim fits over the metal cylinder. The object of the rim is to prevent



Rain Gauge and
Measuring Glass.

the "plashing" of raindrops and to catch any snow that may fall. Care should be taken that the mouth of the funnel is not dented, otherwise the full amount of rain will not be collected. It has been found that the diameter of 5 inches is the most convenient one for ordinary use, and though at some stations a diameter of 8 inches is used, and a consequent greater amount of rainfall may be collected, the results of experiments on gauges "from 3 inches to 24 inches in diameter show that the difference in indications is very small, hardly exceeding one per cent" (Scott).

The gauge is ordinarily examined every day at 9 A.M., and the rain fallen in it during the previous twenty-four hours (if any) is poured into a measuring glass and measured, the amount being entered in the register as having fallen on the *previous* day. The measurement of snow or hail is usually effected by thawing this by means of the addition of a measured quantity of warm water, and subtracting the amount of this latter from the total resulting volume of liquid. Of course the snow may be melted by thawing it in a warm room, but this process is a slow one. It is sometimes said that by measuring the depth of the snow in a place where it has not drifted, and reckoning $\frac{1}{12}$th the depth in inches, *i.e.*, one foot of snow for an inch of rain, we get the amount of rain that would correspond to the given snowfall, but apart from the fact that the snow is not likely to be of uniform density there is an uncertainty arising from evaporation, so that the result will only be a rough approximation.

The height of the rim above the ground for a "ground gauge" should be about 1 foot; the latter should be perfectly level, and to keep it so, as well as to prevent the whole apparatus being blown over by the wind the lower part of the cylinder should be embedded for several inches in the ground, leaving little more than the funnel and rim above the surface. A frequently used contrivance to diminish the effect of the wind as far as possible consists of a shield of wire-netting encircling the mouth of the gauge, this was proposed by Nipher in 1878; the effects of evaporation are reduced to a minimum by making the aperture of the funnel which dips into the receiver as small as possible, and placing the latter in a vessel so that it is shielded from the sunlight (as in the outer copper vessel). It was found that rain gauges placed at an elevation above the ground catch considerably less rain than those near its surface, an effect now known to be due to the action of the wind, as it is stated that a Nipher shielded gauge will catch about the same amount on the roof of a house or other building as on the ground (Waldo).

Of self-recording instruments for the measurement of rainfall a simple form is now on sale by various makers, and a short description of one is given in our chapter on Observatories (chap. xii.).

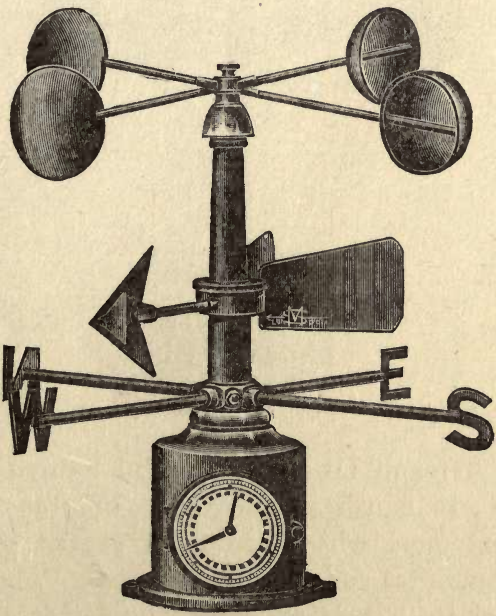
The use of the sunshine recorder has been greatly extended of recent years, and now most seaside and watering places possess one or more of these instruments, and publish the results of these records as an attraction to possible future visitors. The most ordinary form of this instrument is that known as the Campbell Stokes recorder. This consists of a spherical lens of glass whose principal focus lies at a short distance outside its surface. It is mounted on a pedestal, and attached to this is a curved metal framework with three grooves, at a distance from the lens equal to its focal length, the whole resting on a slab whose surface must be horizontal; and this slab should be cemented on to the surface of a wall or other position where it will be freely

Sunshine Recorder.

exposed to the sunlight, and kept in a fixed position. The sun's rays passing through the lens are focussed at some point or other on the surface of the curved metal framework, according to the time of day and the season of the year, and a sheet of cardboard is fitted into one of the grooves. As the sun's position changes the position of its image changes also, and thus burns a trace upon the card, the latter being unburnt when the sun is covered by cloud.

Owing to the sun's varying *declination* (and consequent *altitude*) at different times of the year, its image will fall higher or lower upon the framework, and three sets of cards of different sizes and shapes are provided, the smaller card for winter fitting into the upper groove, the intermediate size for spring and autumn fitting into the middle groove, and the longer fitting into the lowest groove, for summer. The instrument must be so set that the central position must be just opposite to that of the sun at noon, and its image falls upon each card at the point marked noon on the graduated surface of the latter. When the instrument is in adjustment, on a clear, sunshiny day, there will be formed a broad *horizontal* track from sunrise to sunset, the position of this track changing from day to day during the course of the year, as stated above, but the middle point of each day's trace will always coincide with the time of apparent noon. On a cloudy day the trace will be fainter and often broken. It has been suggested to expose a photographic plate towards the north at night-time, and thus obtain a trace of the pole star on clear nights; the record, of course, being broken or absent in cloudy weather, thus supplementing the sunshine recorder for the night hours.

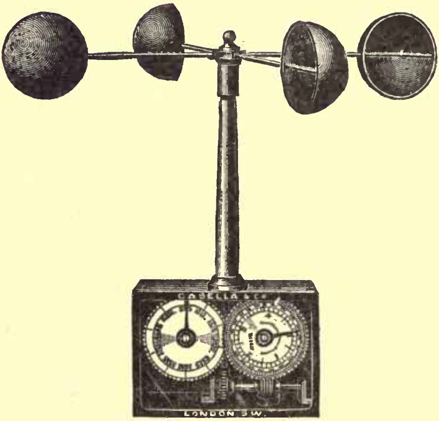
Instruments for wind measurements may be divided into two classes, those which measure



Anemometer with Wind Vane.

its *pressure* upon any surface, and those which record its velocity. The *direction* is indicated by a vane or weathercock, whose construction and manipulation needs little description, though even in this simple instrument errors occasionally arise from the confusion between true and magnetic bearings, the difference in this country amounting from 15° to 20°.

One of the most commonly used forms of "anemometers" for measuring the velocity of the wind is that invented by the late Dr Robinson of the Armagh Observatory, and known by his name. It consists essentially of four hemispherical cups which are fixed at the ends of two horizontal rods forming a cross. These are fastened to a vertical axis, the latter passing through the point of intersection of the rods. The wind causes these rods or arms to revolve, and they are so constructed that a definite rate of revolution corresponds to a definite wind



Robinson's Anemometer.

velocity. The motion is registered by a wheelwork arrangement at the base of the apparatus, being communicated to a system of dials which record the number of revolutions made, whence the speed of the wind may be inferred. There is sometimes an arrangement for marking the numbers of miles of wind on a paper strip fastened to a drum moving regularly by clockwork.

As an instrument for recording pressure, Lind's anemometer may be mentioned. This consists essentially of a glass syphon, one end closed, the other end bent and open to the wind. The limbs of the syphon are vertical, the open end is horizontal. Water is poured in up to a given height, standing at the same level in both legs when the air is calm. When the wind blows, the level will be more or less depressed in the one, and rises correspondingly in the other to a greater or less degree according to its force.

Dines' pressure anemometer is a more exact instrument, but depends on a similar principle.

Osler's and Cator's anemometers are more complicated instruments. In these the pressure against a plate of given area is measured, whilst a resistance is afforded by springs or by weights.

Wild's pressure gauge consists of a rectangular plate, hung on hinges to a horizontal axis. The angle made by this with the vertical measures the force of the wind. Its indications, though sufficiently accurate for light winds, do not show the differences between those of strong force (Scott).

The distribution of rainfall throughout the world is a subject of considerable importance from the economic point of view as well as the meteorological one, for the habitability of any district is largely dependent upon this factor. Even in our own islands the local variations are very considerable, there being a mean annual rainfall of over 160 inches in the lake district of Cumberland, whilst in Lincolnshire the annual precipitation does not usually much exceed 20 inches. Similarly in India, Cherrapunji, on the Khasia hills, has an annual rainfall of 500 inches, whilst in the Deccan there are frequent droughts, and the total amount is far below the average. As a very rough approximation it is sometimes stated that the annual rainfall at any place within the Torrid Zone is about 100 inches, the Temperate Zone has 30 inches, and the Frigid Zone 15 inches. Nevertheless, though it is probably true that as a general rule more rain falls over the Torrid Zone than elsewhere, there are also to be found over the same zone the driest regions of the globe, the Sahara and Arabian deserts, and the great desert of Gobi or Shamo. In South Africa the driest region is probably the Kalahari desert, whilst in America there are the "nitrate" regions of Peru and Northern Chili, and the great Salt Lake district of the United States. The rainfall of

Australia is in general small, and throughout the greater part of the interior of the island continent there falls considerably less than 10 inches per annum.

There are three principal agencies which are most efficacious in bringing about a fall of rain:—(1) mixture of masses of air at different temperatures, (2) ascending currents of air, (3) contact of warm air with the cooler surface of the ground. Of these three agencies, probably the second—ascending currents of air, which by expanding fall in temperature—is the most commonly acting, at least within the tropics. It has been calculated that the temperature of a mass of *dry* air will fall about 1° C. for every 100 metres of ascent (Hann). If, however, the air, as is always the case, contains more or less moisture, the rate of cooling will be considerably less, since condensation, converting some of this vapour into the liquid form, sets free "latent heat," which tends to warm the surrounding air. Nevertheless, the fall of temperature produced by a rise from the surface of the ground to the top of a mountain is very considerable. The heated warm air over the surface of the ocean always containing much vapour in suspension, rising to a greater or less height, sooner or later loses most of its moisture, which falls in the form of rain. Near the Equator, generally speaking, there is an almost continual precipitation in the form of heavy showers, and the fall is greatest when the weather is hottest.

The contact of warm damp air with the colder surface of the ground is the main cause of the greater rainfall on the western part of these islands (Great Britain and Ireland) as compared with the eastern. The prevalent wind being south-westerly, which has blown over more or less of the Atlantic before reaching us, arrives, nearly saturated with moisture, first upon the hilly western portions of the country. The air, being forced to ascend, is cooled by contact with the hilltops, and thus we get the heavy rainfall of our western counties, which, though they are thus wetter, have also a milder temperature than the inland and eastern parts of the country, (partly) through the "latent heat" set free during the process of condensation. The third method of condensation—mixture of masses of air at different temperatures—though considered by some authorities as important, is estimated by Dr Hann as of minor value as a cause of precipitation.

The distribution of rainfall throughout the globe, though in general, as already stated, decreasing from the Equator polewards, is subject to great local variation. In tropical regions the year is usually divided into the "dry" and "rainy" seasons respectively. Thus at Panama the rainy reason is from May to November, the dry season from November to May. In regions where the trade winds blow there is but little rain during the time of their occurrence, whilst the descent of the return trades brings abundance of rain. Since these regions, approximately 30° to 40° N. and S. latitudes, have their rain when the sun is lowest, they may be called the regions of the "winter rains," in contradistinction to those regions where most rain falls when the sun is at its highest.

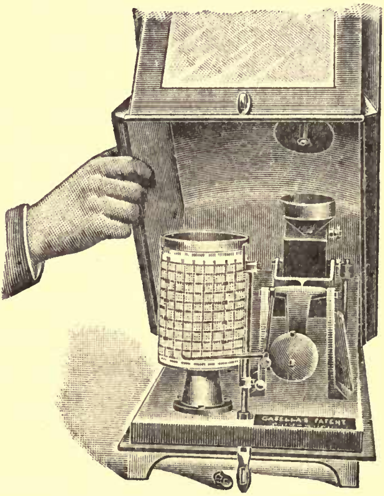
Most of the countries round the Mediterranean, California in America, Cape Colony, etc., come under the former category. On the other hand, in Natal, the Argentine Republic, China, and the Eastern United States, more rain falls during the summer than during the winter periods of the year. In our own islands, though the total amount of rainfall is less than in tropical and sub-tropical regions generally, there is not the same seasonal distinction, though there is, perhaps, a greater amount of precipitation during the winter than the summer months; yet the difference is not a large fraction of the whole amount, so that we may say that we have "rain at all seasons."

It is a general rule that the heaviest rainfalls occur in the western counties in Ireland, Scotland, and England alike, partly owing to the fact that the most rain-bearing winds coming from the south-west reach these regions earlier, and partly owing to the mountainous nature of the western districts, the cooling of the air currents by passing over them producing a deposition of most of the moisture. Maps showing the total rainfall at several thousand stations throughout the United Kingdom, are published annually by the British Rainfall Organisation, founded by the late G. J. Symons, and now under the direction of Dr H. R. Mill.

Note.—By the term annual rainfall, so many inches, is meant the depth of water that would be obtained if all the rain which falls there in a year were collected into one horizontal sheet, and none were lost by evaporation or absorption into the soil. A 5-inch gauge, the area of whose surface consequently

$$=\tfrac{1}{4}\,\pi\,d^2=\tfrac{1}{4}\,(3\cdot1416)(25)=19\cdot63 \text{ square inches}$$

thus collects nearly twenty times as much rain as falls upon each square inch in its vicinity, and so enables measurement of rainfall to the nearest hundredth of an inch (or even less) to be made. *One inch of rain* means that if all the rain falling over any given area were spread out uniformly, it would form a layer having that depth.



Self-Recording Rain Gauge.

MEAN ANNUAL RAINFALL MAP OF THE BRITISH ISLES.

(By kind permission of Dr. H. R. Mill.)

Annual Rainfall.

Below 25	in.	Blank
,, 25–30	,,	Dots
,, 30–40	,,	Faint shading
,, 40–60	,,	Darker shading
Above 60	,,	Black

To face p. 102.

CHAPTER V

WEATHER FORECASTS — TYPES OF CIRCULATION — THE SEVEN FUNDAMENTAL FORMS OF ISOBARS—CYCLONES—SECONDARIES—V-SHAPED DEPRESSIONS—COLS—STRAIGHT ISOBARS—ANTICYCLONES—WEDGES —LOWER AND UPPER WINDS.

From the earliest times inferences as to the probable future course of the weather have been drawn with greater or less certainty from the state of cloudiness, direction of winds, halos, and other optical phenomena, and many "prognostics" are well known and widely prevalent. A very complete collection of these "saws and sayings" is given by Mr Inwards in his "Weather Lore," and though many are little warranted by the actual facts of the case, on the other hand many are of great value, and "in conjunction with other aids to weather forecasting, prognostics will never be entirely superseded, especially for use on board ship" (Abercromby).

The invention and use of the barometer has led to a fresh set of prognostics, and there are still many persons who have great faith in the legends "fine," "rain," "set fair," etc., still to be found on the "weather glass," though these terms are only correct in the broadest and most general sense, and are often without meaning. All such indications and prognostics, however, are of a very uncertain character, and their frequent failures are a subject of common remark. Even as it is now, with the immense mass of statistical information, records of temperature pressure, rainfall, etc., all over the habitable globe, we are in little better position to issue reliable forecasts. The average temperature is thoroughly well known, but no one can say what the *actual* temperature at any hour throughout the year will be; the total amount of rainfall has been measured at some stations for two centuries, but no human being can say with certainty what amount will fall at any given place four days hence.

Occasional attempts to predict the general course of the weather for months ahead may be one and all set down as premature, nay, in some cases they are little better than the charlatanry of the fortune-tellers and astrologers. Such knowledge as we have yet gained is of a purely general and statistical character, leading us to mean and average results, but in no case to inferences for individual future times. The weather forecasts issued by our own and foreign meteorological offices are often remarkably accurate, but are necessarily of the most general character, and *can only be issued a day or so ahead*, though in times of fairly settled weather a good idea may be gained of its course for the next *three or four days.*

This forecasting by means of "synoptic charts," and the information as to the conditions prevailing in surrounding districts, obtained and telegraphed to a central office, has already been alluded to, but we propose here to give a somewhat more detailed account of this branch of experimental meteorology, a science (if it may be called so) as yet only in its infancy. The seven fundamental forms of isobars, already referred to, are the cyclones, anticyclones, secondary cyclones, V-shaped depressions, cols, wedges, and straight isobars. The cyclones, secondaries, and V's enclose areas of lower pressure, the centres being at a pressure more or less below the average; the anticyclones, wedges, and cols enclose regions of higher pressure. It has been found that as a rule cyclones, secondaries, and wedges move eastwards and north-eastwards in our latitudes, whilst anticyclones are often stationary for days or weeks, and occasionally even for months at a time, breaking up rather than moving on.

A cyclone may be defined as a "large disc of nearly horizontally moving air circulating spirally round a central area over which the barometric pressure varies from one-fifth to as much as three inches (of mercury) below that at its border" (Archibald). The diameter of a cyclone varies from 20 to 2,000 or even 3,000 miles, and the form is more often oval than circular, the isobars being usually not quite concentric. Two cyclones differing from one another in the greater or less closeness of the isobars, the general character of the weather experienced during their passage *will be the same*, but the wind will be *stronger* in the former than in the latter case. The main difference between the tropical cyclones causing storms and the cyclones of temperate regions consists in this point.

Tropical cyclones are usually small and move *forward* at the rate of from 2 to 10 miles per hour (Abercromby), but the wind *round them* moves at a very high speed, perhaps 100 miles per hour. Those of temperate regions, on the other hand, have quicker translatory movement, perhaps from 20 to 50 miles per hour, but their rotatory speed (and consequent wind) is much slower. Thus we may consider the "rotatory" phenomena as due to the circulation, the "translational" to the forward movement of a cyclone. In Europe and North America the usual course of a cyclone is towards the *east*, but in the northern tropics hurricanes move towards the *west*. Occasionally, even in our latitudes, a cyclone has a westerly motion, and then the usual prognostics and weather signs are said to "fail."

The usual symptoms of the approach of a cyclone in our latitude are as follows (apart from the fall of the barometer, usually accompanied by the rise of the thermometer):—The air has a close, "muggy" feel, drains begin to smell, persons subject to rheumatism complain of their pains, cirro-stratus and cirrus clouds gradually cover the sky, the sun and moon when seen low down are pale and "watery," frequently surrounded by halos. As the centre approaches, light showers or drizzling rain begins to fall, the wind blows in gusts, and usually from the south-east or south-west. After a while the barometer ceases to fall, and a short bright interval, followed by squally showers, succeeds. The centre is now passed, and the air assumes a brisk, exhilarating "feel." A hard sky with detached masses of clouds of the cumulus type characterises the rear of the cyclone, just as the front is characterised by cirrus or cirro-stratus. The north-west wind "improves men's tempers as opposed to the neuralgic and rheumatic sensations of the front."

Secondary cyclones are small depressions usually associated with larger cyclones, though also found at the edges of anticyclones. The wind usually blows in angry gusts, not in the steady, regular manner of "cyclone wind." The motion of a secondary is generally parallel to that of the primary. Secondaries are frequent indications of rain without much wind. Their sudden formation frequently produces the falsification of previously made forecasts. Contrary to the general rule of rain with a falling barometer, heavy rain, at first in gusts and then more steadily, sometimes for several hours continually, with steady or even slightly rising barometer, accompanies the passage of a secondary.

Allied to secondaries, we have the form of isobars known as V-shaped depressions, the isobars enclosing an area of low pressure, taking a shape like the letter V. These often occur along the southern prolongation of a cyclone, and the point of the V is usually directed southwards in our hemisphere, or else lies in the "col" or region of low pressure between two adjacent anticyclones. Two distinct types of V's are usually enumerated. In the first and most common kind "a narrow strip of cloud precedes an area of rain, followed by detached clouds and blue sky." In the second kind we have the front cloudy, and "half a crescent-shaped area of rain in the rear." The trough of the depression marks off the front of this area, but the rear is ill defined. An example of this kind of circulation bringing with it a "line squall" caused the capsizing of H.M.S. *Eurydice* off the Isle of Wight in 1878. The usual sequence of weather, as this form passes over a station, is from blue sky to cloud and wind from the south-west, with falling barometer. Then a heavy bank of cloud comes from the north-west, passing over with a squall; the wind suddenly changes to north-west, and the barometer rises. After the squall, driving rain continues for some time, gradually ceasing, and the sky clearing once more. Many of the "southerly bursters" of Australia are said to belong to the class of V's in which rain falls in rear of the trough; the point of the V is here turned northwards, whilst the wind is north-east in front, and south-west or south in the rear.

The col, as just mentioned, is a neck of low pressure lying between two anticyclones. In the middle there is usually no wind, whilst on the edges the wind blows according to the usual rule of isobars. The weather is generally dull and gloomy, and frequently violent thunderstorms occur (in summer) during the prevalence of these conditions. The col does not itself move, and no regular sequence of weather can be assigned to it.

Straight isobars are sometimes found near the northern edges of anticyclones. They rarely persist for long, and are soon followed by a cyclonic depression. They thus usually indicate cloudy, unsettled weather, with some wind, soon to be succeeded by more or less rain, though the air is drier than in the case of cyclones. "Visibility," "the sun drawing water," and "audibility" frequently occur as accompanying this form of isobars.

In every respect contrary to the cyclone is the next most frequent type of circulation, called, from its general opposition in properties, the "anticyclone."

In this the isobars are usually much wider apart, than is the case with those composing the cyclone, and the gradient of pressure is *upwards towards the centre*, diminishing gradually towards the outer portions. Whilst the cyclone is usually in fairly rapid motion, the motion of an anticyclone is very slow, and sometimes the system remains almost stationary for days or weeks at a time, finally breaking up and being replaced by a cyclone. The circulation round the centre is "clockwise," but the wind is much less in force than for cyclonic disturbances, as is shown by the greater distance apart of the isobars. During the prevalence of an anticyclone we have in summer, blue sky, hot sun, and little wind; in winter, frost and fog, and sometimes biting east winds, with gloomy black sky. In the centre of the anticyclone there is a dead calm, whilst the circumferential winds are usually slight and centrifugal, or slightly curved *outwards*; the wind in a cyclone being centripetal or *incurved.* Extreme dryness, accompanied by heat in summer (though sometimes slight showers fall), and cold, frosty (sometimes also foggy) weather in winter, are the constant characteristics of this type of circulation. Anticyclones are the most persistent types of atmospheric circulation.

Wedge-shaped isobars are projecting areas of high pressure moving between two cyclones, and may be regarded as the converse of V depressions, just as anticyclones are the converse of cyclones. The wedge may point in any direction, but most commonly is directed towards the north. On the front or eastern side the weather is bright and the sky clear, the wind being of moderate force, and blows round according to the general law of gradients (from the north-west on the east side); in the centre there is a calm, and on the west side the wind is south-west, the sky becomes overcast, usually with cirro-stratus clouds, and next comes rain from the following cyclone.

Thus the sequence of weather, when the wedge travels eastwards, is fine, with north-west wind and rising barometer; then calm and mist or fog; then halo and gloomy sky, falling barometer and rain, with south-west wind from the new cyclone. Thus the prognostics of halos, strips of cirrus, known popularly as "Noah's Ark," etc.

It is to be remarked that all cyclones are not preceded by a wedge, but "only those which roll, as it were, along the northern edge of large stationary anticyclones" (Abercromby). Appearances of the sky characterising the front of a wedge are signs of coming rain, of the very opposite kind to those of the rain prognostics of a cyclone.

Thus in a very broad, general sense we may consider cyclones, V-shaped depressions, straight isobars, and cols as indicative of unsettled conditions; anticyclones and, to a less degree, wedges, high-pressure areas of fine weather, the former of a more or less permanent character, the latter transient and "too fine to last." We may distinguish between the rain of a cyclone, which is heralded by great dampness of the air, the rain following wedges, due also to the succession of a cyclone, though the air in the wedge is itself dry, and the slight showers associated with straight isobars.

We have just given some account of the course of circulation, direction of winds, etc., in these various types of isobars, and must now proceed to the consideration of the upper currents associated with these.

The surface winds of the cyclone may be described as moving in an "ingoing spiral," more incurved in the right front than elsewhere, and less incurved as we approach the centre, than in the regions outwards.

The upper currents, on the other hand, blow outwards in front (in the fore part of the cyclone), their direction makes a considerable angle with that of the lower currents, but at the rear they are more nearly parallel to the latter. For the anticyclone also, the surface winds and the upper currents are even more opposed in direction than is the case for cyclones; the former blow spirally *outwards* in the clockwise direction, the latter *inwards*. In every case the upper currents move more quickly than those near the surface; this is, no doubt, partly due to the decrease of friction, just as winds over the surface of the sea blow more strongly than on the neighbouring lands. The increase of speed upwards, from observations made first by Stevenson, of Edinburgh, later by Professor Archibald, and more recently by the observers at Blue Hill and elsewhere, appears to be very considerable. Whilst the surface winds experience the full effects of friction with the ground, at a very small altitude this effect rapidly diminishes. Professor Archibald found that the average velocity at 1,600 feet is just double that at 100 feet, and still continues to increase for greater heights. Clayton's observations at Blue Hill give for the level of the stratus clouds (1,670 feet), an average speed of 19 miles per hour, increasing to 24 at 5,326 feet (height of the cumulus), and velocities of 71 and 78 miles per hour respectively, for altitudes of 22,000 feet (cirro-cumulus), and 29,000 feet (cirrus). In winter the speeds are greater than for summer, and speeds of the upper cirrus clouds amounting to as much as 96 miles per hour are recorded. The speeds noted in European localities for the upper air seem to have usually somewhat less than these values. (*See* also chap vii.)

CHAPTER VI

MORE DETAILED DESCRIPTION OF COURSE OF CIRCULATION—WEATHER IN (1) CYCLONES, (2) ANTICYCLONES—SPECIAL VARIETIES—WHIRLWINDS—TORNADOES.

THE name "Cyclone" (from the Greek κύκλος, a circle), though popularly applied only to the violent storms of the tropics (the air in which moves round and inwards towards a central region, hence the name), is applied by meteorologists to any portion of air moving in such a manner, the pressure at the centre being lower than that at the borders; the difference between one cyclone and another being (1) a difference in size; (2) difference in shape, and closeness of the isobaric lines. It is upon this latter that the force of the wind depends, as we have already seen; the ordinary cyclones of (usually unsettled) weather, and those which cause violent storms, differ mainly in this respect; but the latter are also usually much smaller in size than the former.

In our own country, in addition to this circulatory or spiral motion of cyclones, they have *usually* a motion of translation from south-west towards north-east, though they are sometimes stationary; at other times they move in the opposite direction, and occasionally fill up without moving on.

The weather signs at the front of a cyclone are usually those already mentioned, gloomy, close, and muggy weather, drains smelling offensively, the sun and moon seen dimly surrounded by halos, and the cloud formations of a cirro-stratiform type. If now the cyclone remains stationary, or dies out, or moves in a different direction, then these prognostics of coming bad weather would be said to fail. During the course of a cyclone travelling more or less centrally across any district, we find the following accompaniment of weather, cloud, etc., and various popular sayings are associated with different phases. The first signs of approach of a cyclone, "the front," is often heralded by halos, seen round the sun and moon, commonly when they are low down in the south-west. Next follows denser clouds, giving rise to the "watery sun," seen dimly through their greater thickness. After this follows rain, at first slight, but soon more continuous and heavy, accompanied by driving wind. All this time the barometer is falling continuously with greater or less rapidity. The wind at first (assuming the the usual direction of a cyclone in this country, from south-west towards north-east, roughly speaking), is from the south-east, and moderate in force, but changes in direction and increases in force, as the depression advances; veering towards the south, and then becoming south-westerly, perhaps increasing in force to a gale. Now the barometer will begin to rise again, the centre line or trough having passed, and the wind suddenly veers round, or rather "jumps" towards the west or west-north-west, its force being much greater than has hitherto been the case, rain coming on more heavily than ever. This ceases after a while, the barometer continuing to rise, and patches of blue appear in the sky with "rocky" cumulus cloud and moderate wind.

Lastly, after a few "clearing" showers, the wind falls to a gentle breeze, the heavens becoming clear and cloudless, and the cyclone has passed. When the observer is situated exactly on the path of the cyclone centre the wind "jumps" or changes when the centre passes without "veering" or "backing" through the intermediate directions, from south-west to north-east; if he, as is usually the case, is to the south of the centre, the wind "veers," very rarely for this country, when the cyclone centre is to *his* southward the wind "backs." If the wind changes with the "sun," *i.e.*, from east by south to west, or in the same direction as the apparent motion of the heavenly bodies in the sky, this is called "veering"; if its change is in the opposite direction, *i.e.*, from westwards by south to east, or from east by north to west, it is said to "back" or change against the sun. A change of direction, such as that from south-west to north-east, without either veering or backing, such as occurs after the centre of a cyclone has passed directly over the observer's position, is conveniently called a "jump." Mr Abercromby quotes the following prognostic with reference to the "backing" of the wind:—

> "When the wind *veers* against the sun
> Trust it not, for back 'twill run."

This he explains by the usual sequence of disturbance. When in Northern Europe a cyclone passes to the south (a rare phenomenon), thus producing the backing of the wind against the sun referred to, it is almost always followed by another cyclone to the north, which brings more bad weather and fresh changes of the wind.

From the general indications given by clouds, wind, and barometer as outlined above, the observer can easily ascertain his position with regard to the disturbance, and its general course. The various directions of the wind in the different portions of a cyclonic disturbance are related to the pressure (in different parts) by the "law" of Buy Ballot, given more fully in our chapter on the Winds (viii), sometimes enunciated thus:—

"Stand with your hands stretched out on either side and your back to the wind, then, in the Northern Hemisphere the centre of the cyclone will be to your left hand; if you are in the Southern Hemisphere the centre will be to your right."

This form, however, ignores the incurvature of the wind, which, instead of blowing directly along the isobars, makes a considerable angle therewith; this varies with position on the surface of the globe, being also different for storms on land and on sea. The "inclination" was found to be 62° for the Philippine Islands (latitude 14°); in Bengal (latitude 20°) it was 57°; over the Atlantic 30°; in England only about 20°; thus apparently greater for equatorial regions than for stations further northwards. From this it follows that the old law of storms, which supposed the wind to "blow in a circle" directly along the isobaric lines, is quite unreliable for tropical latitudes, where the deviation is often considerable. Thus it sometimes happened that by following this rule, in the old sailing-ship days, a captain might sometimes run his ship directly into danger when seeking to avoid it. Whilst cyclones form, perhaps, the most prominent feature of the atmospheric circulation in our latitudes, they are less common in the tropics, though of a more dangerous type, as has been mentioned, smaller but with much greater and more violent wind motions, and it is from these that the word "cyclone" has acquired its popular meaning of a fearful storm.

The researches of Piddington, Redfield, and

Dove on Indian, American, and European cyclones respectively, established the true form of the movements of wind, that the latter circulates in a spiral curve round the centre or point of lowest pressure.

The late Dr Meldrum, for many years Director of the Royal Alfred Observatory and Government Meteorologist at Mauritius (whose researches on cyclones have recently been utilised by Mr Maunder of Greenwich to point out an unexpected relation between their sequence in tropical latitudes and the sun's rotation period), by his work largely helped to develop a more satisfactory set of rules than those afforded by the "circular theory." Even so, all that can be done is to give rough general rules, for, as pointed out by Dr Meldrum, in some cases the wind, instead of blowing at *right angles* to the radius, blew directly towards the centre (Scott). The modern rules now advise the mariner "to avoid" running before the wind, to lie to on the starboard tack (*i.e.*, with the wind on his right) in the Northern Hemisphere, or on the port tack (wind on left) in the Southern.

Tropical cyclones occur more frequently in September and October for the Northern Hemisphere; in February and March, the "cyclone seasons," for the Southern; or more generally in the summer and autumn of both hemispheres. Off the Indian coasts they are most common and dangerous at the changes of the monsoons during May and October respectively. At times there is a difference of not less than 2 inches of pressure (mercurial barometer) between the centre and outer circumference of a cyclone. During one storm the barometer at Marie-Galante in Guadaloupe fell from 29·646 inches to 27·953 inches in the course of seventy minutes, between 6.30 and 7.40 A.M. on 6th September 1865 (Buchan).

It sometimes happens that such a cyclone will travel from the tropics northwards towards Europe and more temperate regions, where it will become a much milder phenomenon. This is another proof that the ordinary storms of Europe are phenomena of the same nature as hurricanes, though differing from them not only in intensity, but probably in the shape of the storm area, and also apparently in the unequal development of the wind from the different points of the compass (Scott).

Calculations have been made by the curious as to the amount of energy developed in some of these disturbances. For instance, Professor Reye of America calculated that the Cuban cyclone of 5th October 1844 used up 473,000,000 units of horse-power in three days.

As a theory of the cause and movement of cyclones, a brief outline of Ferrel's views may be of interest. Ferrel, sometimes called the "Newton" or the "Father of Modern Meteorology," originally an elementary school teacher, who by his original researches and other work has so largely added to our knowledge, constructed a consistent theory of these phenomena.

By assuming an inflow towards and an upflow over a given area, he showed that (neglecting friction) the air would tend to rotate round a central area, at the inner portions of which the pressure would be very low, but this would gradually increase from the centre outwards, the whole moving in a *direct* or counter clockwise direction. Outside of this area there would be another area moving in the opposite or clockwise direction. The interior region would thus be the *cyclone*; the outer a kind of anticyclone or pericyclone. The effect of friction would be to somewhat modify this ideal state of affairs; the pressure near the centre would be low, but not quite so low as would otherwise be the case, the (interior) motion of the inner portions being somewhat more "centripetal" (towards the centre), that of the outer part "centrifugal" (outwards).

The clear, calm region usually only a few miles in extent, at the centre of a tropical cyclone, sometimes called the "eye" of the storm, was explained by him.

Some modern "specialists" consider that extra tropical cyclones, at least in part, are due to somewhat different causes from those of the tropics. It is well known that stormy conditions, heavy rain, etc., are, on the whole, more prevalent in winter than in summer, and it has been thought that they are due to eddies or whirls in the upper "return currents" flowing over from the Equator, which are crowded into the "narrower latitudes." These eddies cause the lower air nearest the surface to ascend; this air forms clouds, whence sometimes rain falls, but the movements are less violent near the ground than in the upper regions.

The general direction of motion of cyclones eastward in these latitudes has already been alluded to. They appear to be governed chiefly by the prevalent west wind, both upper and under, and are carried along like eddies by the current. They often exhibit a remarkable tendency to follow the same course, several successive depressions quickly succeeding one another. Thus during weather of the "westerly" type, in Great Britain, when the depressions are so far south as to cross that island, the centres have a decided tendency to traverse either the line of the Caledonian Canal in Scotland, or the low-lying ground which separates the valleys of the Forth and Clyde (Abercromby.) Other cyclones coming in from the Atlantic often hug the coast of Norway instead of going north-east.

Mountain chains also powerfully influence their direction. For instance, the Alps forms a natural boundary between the Mediterranean weather and that prevailing in the more northern parts of Europe; the Himalayas, to the north of India, also, even more powerfully influence the weather conditions of that great country. This tendency of cyclones to follow certain definite directions is, of course, of great importance in connection with forecasts as to their probable course and duration. The influence of heat in determining their course has also been considered by Dr Bebber and others. The former has enunciated the following relations, especially for Central Europe:—

"When the distribution of air pressure and temperature are in the same sense, then the depression is propagated nearly in a direction perpendicular to the temperature and pressure gradients; if they are distributed in the opposite sense the motion of the depression ceases or is checked."

He considers pressure to be the more important factor in determining cyclone motion in winter, whilst in summer, temperature difference is the predominant influence. With regard to the "sense" of temperature and pressure gradients, the following definition is given:—

"If the highest pressure and highest temperature are both to the north, or both to the south of a cyclone, they are said to be in the same sense (and the depression will move at right angles to both). But suppose pressure was highest to north, and temperature highest to south, then these two elements are said to be distributed in the opposite sense, and the cyclone would probably be arrested in its usual eastward course" (Abercromby).

Cyclones frequently exhibit a tendency to move round anticyclones usually in such a manner as to keep the anticyclones on their right in this hemisphere, whilst occasionally they appear to move round one another, or again the phenomenon of two cyclones moving round a common centre is presented.

As already stated, whilst the surface currents in a cyclone move after the manner of an *ingoing* spiral, but with their direction less incurved towards the centre, in the upper parts of the disturbance, at heights above 10,000 feet from the earth, the wind blows in a more irregular spiral *outwards*, being in front very much inclined outwards, but in the rear nearly parallel to the lower surface currents. At intermediate heights the course of the wind is considered to be nearly parallel to the isobars, or moving almost in a circular, or more strictly oval, manner, since few cyclones are even approximately circular, the late Professor Loomis stating that in the United States a circular "cyclone" does not occur more than once during the course of the year, the average ratio between the longest and shortest diameters being about 1·94 to 1, or roughly, rather less than 2 to 1. We have already detailed the general distribution of cloudiness in a cyclone, but the actual circumstances vary somewhat in different cases. The most common occurrence of rain with low pressure does not, however, prevent occasional instances of an exception to the general rule being sometimes perceived. In some cases well-marked and large depressions have been formed, but the barometric reading at the centre was only slightly less than on the outside, perhaps not lower than 29·7 inches (of mercury), the gradient is consequently very small, with light winds, small and slow fluctuations of pressure; unaccompanied by rainfall, or at most very slight showers have fallen.

We next come to consider the large often stationary areas of high pressure from which the air often flows outwards, to feed the cyclones, whose characteristics are in so many respects opposite to those of the latter that the name of anticyclone has been universally applied to them. Anticyclones are generally of much larger size than cyclones, and sometimes cover a whole continent, or extend half over the ocean, and are very persistent phenomena. The pressure is highest at the centre and the isobars are more nearly circular than those surrounding the cyclone centre, and much wider apart; in consequence there is usually but little wind anywhere. There is practically a calm in the central portion, but on the outer parts of the system the wind blows round the centre in the clockwise direction. Like the wind of cyclones the surface wind direction is not along or parallel to the isobars, but spirally outwards. Just as with depressions the surface and the upper winds are opposed in direction, the upper currents blowing spirally *inwards*, their direction being more inclined to the isobars than the lower. The whole system, though often at rest and persisting till it breaks up, occasionally moves slowly along, usually in a direction east to west, or sometimes north-west to south-east.

During the summer-time this type favours dry, hot weather, in winter east wind and overcast conditions. Often the morning is somewhat hazy or foggy, but this mistiness is usually dispersed by the power of the sun's rays; the broad features of anticyclone weather being put as blue sky, dry cold air, hot sun, and hazy horizon, with very little wind, the type called by Abercromby "radiation weather." In summer, mist in the morning and evening, with fine, hot, cloudless day; in winter similar conditions, but more pronounced fog, and often instead of a clear sky, overcast, gloomy, rainless weather, sometimes accompanied by the well-known east wind whose presence is so unwelcome:—

"When the wind is in the east,
'Tis neither good for man nor beast."

Many indications and popular sayings are very familiar, some being common to all parts of the world. The far flight of birds, wild animals disporting themselves in the open air, and the exhilarating effects of fine bright weather upon human beings as well as the animal creation generally, are well-known accompaniments. The prevalence of morning and evening mists during hot weather, of fogs, white or black, as the case may be, and frost during winter (the necessary accompaniment of the absence of wind during anticyclonic conditions), as also the veering of the light breezes with the sun "in by day, and out by night," the land and sea breezes due to unequal heating of sea and land, experienced at maritime stations, are all more or less common phenomena accompanying this form of isobars.

Whilst in cyclones it is considered that we have to deal with an ascending current, for anticyclones the current is a descending one, and, as stated, sometimes serves as a "feeder" to the former. The ascending damp air of the cyclone more or less nearly saturated with moisture favours precipitation and consequent rainy conditions, whilst the air being drier, and such moisture as is present far from the temperature of saturation, in the anticyclone, it in general favours fine and settled conditions of weather.

It has been already stated that both forms of circulation in general depend upon one another, and that cyclones frequently travel round anticyclones, near whose edges they have been formed, though it sometimes happens that they will travel far from these latter, occasionally moving not only across the Atlantic into Europe, but even passing thence to Asia.

In addition to the more common forms referred to, special groups of local disturbances of smaller size, variously known by the names of whirlwinds, tornadoes on land, and water-spouts on the sea, the simoon or dust cloud of the desert, the hurricanes of the West Indies, and the typhoons of the China Seas, are all related to cyclones, though "the motion of the wind in storms of the eddy type is probably more truly spiral, incurving towards the centre, than circular" (Scott).

The whirlwind or tornado may be described as a mass of air in rotation round an axis usually nearly vertical. It may be as much as 200 feet in height, but its breadth does not usually exceed 10 feet. The harmless "dust whirl" of the roadside and the terrible tornado of America are extreme examples, whilst the "simoon" of the desert is a whirlwind carrying sand and dust. When the whirl is large and the air moist we sometimes get a thunderstorm, such as accompanies the "pampero" of the Argentine Republic, which is described as a south-west wind, ushered in by a sudden squall, with rain and thunder and a typical form of cloud wreath. In northern latitudes a similar kind of disturbance is known as a "line squall" (Abercromby).

The most characteristic feature of the tornado is its funnel or spout, the cylinder of air in rotation, whilst the system moves forward, usually in a north-east direction at a rate of about 30 miles per hour. The rotation is of a somewhat complex character; in addition to the counter-clockwise or cyclonic motion there is usually a violent upward current, also a rising and falling motion, the end of the spout sometimes rising from the ground and then descending again, whilst the axis is seldom upright, but sways slightly to and fro. Rain and thunder usually accompany this manifestation. Great damage is done by its destructive violence — houses, trees, fences, churches, etc., being blown down or carried up into the air for a great distance. It has been estimated that the velocity of the wind rotating near the centre of a tornado may reach as much as 500 miles per hour; whilst the upward velocity may sometimes attain to over 100 miles per hour. The central column of rarefied air being cooled by expansion, any vapour within it is condensed. Thus sometimes a "water-spout" is produced. That this water is not drawn up from the sea is shown by the fact that even when a water-spout passes over the sea, the water in it is quite *fresh*, and not at all salt. The funnel shape of the waterspout or tornado clouds is considered to be due to the increased pressure of the air near the surface. Above, the absence of friction and the pressure from below causes the central rarefied area to extend somewhat, but lower down there is increased internal pressure, and the rotating air is confined to a narrow space.

Tornadoes appear to be more common in the spring and early summer, whilst in autumn and winter they are of very rare occurrence. They usually occur on sultry days, and either in the south-east, or right front of cyclones, or in front of the trough of V depressions (Abercromby).

The destruction done by these fearful, though fortunately short-lasting manifestations, which "break the monotony of a tropical calm," has been so often described in glowing terms by different writers that it seems hardly necessary to repeat the well-worn tale. Those who are fond of complaining of the badness of our own weather may at least be reminded that we have much to be thankful for in our exemption from such catastrophes; though besides this purely negative benefit, the existence of many positive advantages alluded to in the course of this work may with more justice cause our own climate (or at least that of the more maritime western regions), to be regarded as *one* of the best in the whole world, though perhaps that of certain stations in the Southern Hemisphere is more salubrious.

CHAPTER VII

CLOUDS — HOWARD'S NOMENCLATURE — CIRRUS — CIRRO-CUMULUS — CUMULUS—STRATUS—CIRRO-STRATUS—CUMULO-STRATUS—NIMBUS—HEIGHTS OF DIFFERENT KINDS OF CLOUDS—MOTIONS OF CLOUDS AND AIR CURRENTS—FOGS, MISTS, ETC.—DUST PARTICLES OR OTHER NUCLEI NECESSARY—CLOUD "PROGNOSTICS" OF WEATHER CHANGES.

It has been often said that the study of clouds is one of the most important elements necessary for successful forecasting of coming weather. More than a century ago, Howard, in his essay on the "Modifications of Clouds," proposed the nomenclature for the different kinds which is now universally adopted. "Clouds," says he, "are subject to certain distinct modifications, produced by the general causes which effect all the variations of the atmosphere; they are commonly as good visible indications of the operation of these causes, as is the countenance of the state of a person's mind or body." He first discriminates the three simple kinds, cirrus, cumulus, and stratus, the names being derived from the Latin, and nearly correspond to their general appearance. He defines cirrus cloud as "parallel, flexuous, or diverging fibres, extensible in all or on all directions" (*nubes cirrata*). The cumulus (*nubes cumulata*) cloud is a "convex or conical heap increasing upwards from a horizontal base." The third form, stratus cloud (*nubes strata*), is "a widely extended, continuous, horizontal sheet, increasing from below." Of these three forms the cirrus clouds are the finest and most lofty; cumulus, more dense and formed in lower regions of the atmosphere; stratus, the lowest form, usually forming in the evening and dissipating towards the next morning. Howard distinguishes four intermediate forms, the cirro-cumulus, the cirro-stratus, the cumulo-stratus, and the cumulo-cirro-stratus or nimbus. Other forms are sometimes given, but these seven kinds will describe 90 per cent. of all skies (Abercromby). Howard's definition of these intermediate forms we take from his famous essay, mentioned above. The "cirro-cumulus" consists of "small, well-defined, roundish masses," in close horizontal arrangement. The "cirro-stratus," "horizontal or slightly inclined masses, attenuated towards a part or the whole of their circumference, bent downward, or undulated, separate, or in groups consisting of small clouds having these characters." Next comes the "cumulo-stratus," "the 'cirro-stratus' blended with the cumulus and either appearing intermixed with the heaps of the latter or superadding a widespread structure to its base. The seventh form, nimbus or cumulo-cirro-stratus, 'the rain cloud.' A cloud, or system of clouds, from which rain is falling." "It is a horizontal sheet above which the cirrus spreads, while the cumulus enters it laterally and from beneath."

In addition to the above seven well-marked forms some writers distinguish between *cirro-stratus* and *strato-cirrus, cirro-cumulus* and *cumulo-cirrus*, according as one or other character predominates, Howard's forms cirro-stratus and cirro-cumulus being each subdivided into two. Captain Wilson Barker[1] proposes a very simple classification, considering all clouds as belonging to one or other of two types:—(1) The Cumulus or heap type; (2) the Stratus or large sheet type, including all forms save Howard's cumulus under the second heading. Of all these forms the *cirrus clouds* are those which have the greatest elevation and variety of extent with least density. They are the earliest indications of change after a period of fair, settled weather, signs that this is to be followed by less favourable conditions.

At first there appears a few threads "pencilled, as it were, on the sky." These increase in length, and new ones are added laterally. Often these first threads serve as stems to support numerous branches, and from these in their turn other branches spring.

Owing to their great height, cirrus clouds though often in fairly rapid motion, seem more slowly moving than clouds of other forms. It is fairly certain that they consist of small ice

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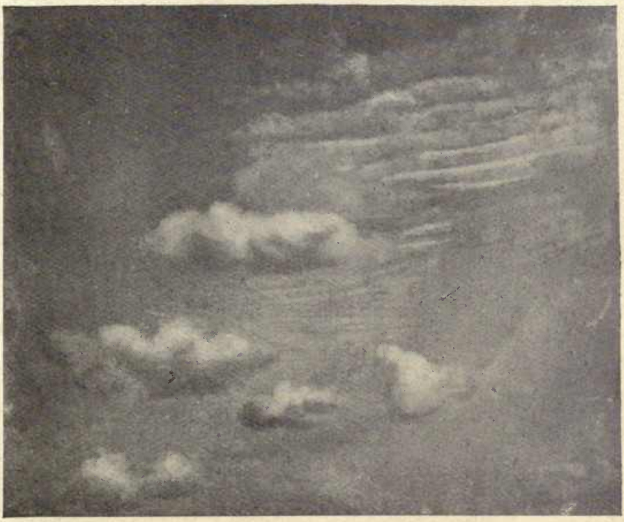
[1] Essay on "Clouds and Weather," 1895.

crystals, whence their effects in causing halos and other optical phenomena. Investigations by Hildebrandson in Sweden and the Rev. Clement Ley in this country have added considerably to our knowledge of atmospheric movements in the upper regions of the air. Cirrus clouds seem to be found in all parts of the earth, but those seen in tropical regions are probably at a greater altitude above its surface than the polar ones. With regard to their duration, Howard remarks that this varies from a few minutes to many hours, being long when they appear alone at great heights, and shorter when they are formed lower and in the vicinity of other clouds. In fair weather the sky is seldom quite free from small groups of oblique cirrus, whilst continued wet weather is attended by horizontal sheets, which subside quickly and pass to the cirro-stratus form. Before storms they appear lower and denser, and usually in the quarter opposite to that from which the storm arises. This form of cloud is often called "mare's tails," more especially when it is curved in form. In observing these clouds, it should be noted whether they are developed in any particular region of the sky rather than another, as well as the relation between their longitudinal extension and the direction in which they are moving.

The *cirro-cumulus* is also a lofty cloud, though usually less high than the cirrus. It differs from the latter in being of a more rounded form,



CUMULUS AND HIGH STRATUS.

CIRRUS.

(Photos by Capt. Wilson Barker, F.R.S.E., F.R.Met.Soc., &c.)

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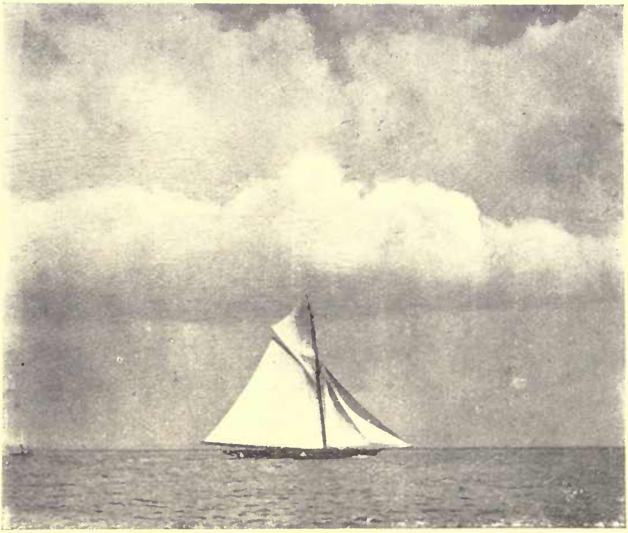

SQUALL CUMULUS.

CUMULUS.

(Photos by Capt. Wilson Barker, F.R.S.E., F.R.Met.Soc., &c.)

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consisting usually of small, detached masses, sometimes compared to a flock of sheep lying down, or the markings on the back of mackerel, whence the name "mackerel sky." It seems to be formed from a cirrus or from a number of small separate cirri, by the fibres collapsing and becoming small, roundish masses, the change taking place either through the whole mass at once, or gradually from one end to the other. This form is frequent in summer during warm, dry weather, and is more sparingly seen in intervals between showers, or before thunderstorms, when very dense and compact masses in close contact are often visible.

The *cumulus* cloud, commonly called the "wool pack," is formed by an ascending current of air whose vapour is rapidly condensed. It is the densest kind of cloud formed in the lower atmosphere. Its lower surface is roughly plane, whilst its upper rises into conical or hemispherical heaps, which sometimes "continue nearly of the same bulk or rapidly rise to mountains." If remaining unchanged in size they are usually numerous and near together, when swelling they are few and far apart; in either case their bases always lie nearly in one horizontal plane. These horizontal bases are, of course, evidence of the existence of strata of air of different temperatures. If the lower stratum be at a higher temperature than the upper it can contain more moisture, and thus will dissolve any portions of the cloud which descend into it, so that the cumulus cloud appears to stand on the surface of separation between these two layers of different temperature. In fair weather the variations of these clouds are often periodical during the course of the day. They begin to form some hours after sunrise, arrive at their maximum size during the afternoon, at the hottest time of the day, and then diminish, totally disappearing towards sunset. If, on the contrary, they increase rapidly in size, sink downwards, and do not disappear in the evening, rain may be expected. The formation of large cumuli to "leeward" in a strong wind indicates the approach of a calm with rain; if they do not subside, but continue to rise towards sunset, thunder is to be expected in the night. In winter time the appearance of cumulus in the south after a fine day often indicates approaching snow.

The *stratus* is a cloud lying in horizontal layers or strata, whence the name. Howard applied this term also to ground mists and fogs, but this is now discarded by meteorologists. It may be considered as the "cloud of night," since it owes its origin to the evening mists and grows denser during the night, dissipating again towards morning. The air being tolerably still and radiation from the ground going on, the general mass of the atmosphere above it cooling gradually, some stratum arrives at the dew point temperature and its moisture is condensed into cloud. The pure stratus cloud is an accompaniment of fine weather, and if stratus at night be followed by diffuse fog in the morning we have generally settled atmospheric conditions.

The *cirro-stratus*, according to Howard, appears to result from the subsidence of the fibres of the cirrus to a horizontal position; at the same time they approach one another laterally. The form and relative position often suggests "shoals of fish." The structure is always thickest in the middle and thinner towards the edges. This form of cloud often precedes wind and rain, the nearer or more distant approach of which may sometimes be inferred from the greater or less permanence of these clouds. Owing to the great extent but little perpendicular depth of this form, the sun or moon may often be seen shining through it surrounded by a halo, so that the appearance of these phenomena is often regarded as a sign of approaching foul weather. It seems fairly certain also from these phenomena that the cirro-stratus clouds are largely composed of frozen particles of vapour.

The *cumulo-stratus* cloud is a compound of cirro-stratus resting either on the top of a cumulus or crossing an isolated patch of the latter. It may be regarded as the cumulus cloud passing gradually into the nimbus form. It is usually a forerunner of rain or snow, according to the season of the year.

The *nimbus* cloud is a name loosely given to any kind of cloud from which rain falls, so that the term may be applied rather vaguely to different species. Abercromby distinguishes two kinds—the *cumulo-nimbus*, the rocky, cumulus cloud from which rain falls in squalls or in showers; and *pure nimbus*, a flatter cloud more like heavy strato-cumulus, that forms from or under cirro-stratus. The name cumulo-cirro-stratus, suggesting its mode of origin, has been already alluded to. "The reason for making nimbus a class of its own comes from the fact that a sudden striking change comes over the look of the upper surface of a cloud the moment rain begins to fall" (Abercromby). This change is *possibly* associated with the discharge of electricity at the moment of precipitation.

In addition to these principal varieties a number of minor forms, some of which are of importance in judging coming weather, may be distinguished. Sometimes before the approach of a cyclone a blue sky becomes white, then grey, and drizzling rain falls without the formation of any true cloud form. For this Mr Ley has given the name "cirrus haze" or "cirro-nebula." Small detached clouds seen in rapid motion under any mass of cloud just before the precipitation of rain are frequently called "scud," or sometimes *fracto-cumulus*. Before the advent of squalls and thunderstorms there is sometimes seen a long roll of narrow black cloud in rapid motion, and this form goes by the name of "cloud wreaths."

With regard to the height above the surface of the ground at which the various cloud forms exist, we may class cirrus, cirro-cumulus, and cirro-stratus as high clouds, since they often exist at an altitude of 20,000 to 30,000 feet; cumulo- and strato-cirrus forms are found at intermediate altitudes, whilst cumulus, stratus, and nimbus are low, many being below 2,500 feet. The levels for Upsala of the principal varieties in summer have been given as:—cirrus forms, 20,000 to 27,000 feet; middle forms, 12,000 to 15,000 feet; cumulus, nimbus, and stratus, below 6,000 feet. Though these altitudes vary with latitude and season of the year they serve to illustrate the principle, "that clouds everywhere tend to form at a few definite levels, widely separated from each other."

Motion of clouds.—Low-lying clouds usually move in the same direction as that of the wind felt at the surface of the ground, though in mountainous regions they are subject to local variations. Their motion is, however, always more rapid than that of the air current close to the ground. Clouds at great altitudes have been carefully studied, especially in recent years, by the observers at Blue Hill, near Boston, U.S.A., and elsewhere, and it has been shown that at a height of about 5 miles the movement is practically three times as fast in summer and six times as fast in winter as the currents at the earth's surface.[1] As a general rule, the greater the altitude the faster the movement. Their motion, too, is often in a different direction from that of the surface currents, and sometimes we find several layers of clouds floating at different heights, each moving in different directions.

Fogs and mists are closely related to clouds. Aqueous vapour rising by evaporation from the ground is itself invisible, but it becomes condensed in the form of minute droplets, with the liberation of its latent heat. At any definite temperature air has the power of maintaining a certain quantity of aqueous vapour in the gaseous condition, this being greater as the temperature is higher. When the air contains the maximum quantity of vapour for a given temperature it is said to be saturated, and the smallest diminution of temperature causes a portion of the vapour to leave the gaseous condition and become "precipitated," as it were. Two masses of air of different temperatures mixing together, each saturated with moisture, producing a mixture of an intermediate temperature, a portion of their moisture is thus condensed and a fog is formed. The condensed particles having a tendency to form on solid matter floating in the air, such as dust and soot, etc., we get the black fogs of London and other large towns. No fogs can

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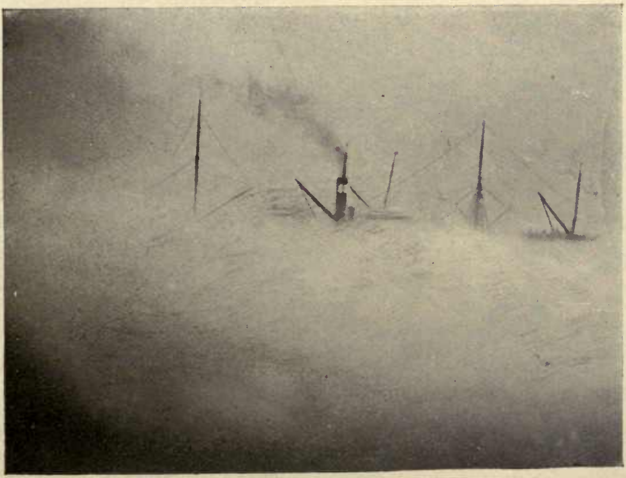
[1] Inwards, presidential address to Royal Meteorological Society "On Some Phenomena of the Upper Air."

CIRRO CUMULUS.



GROUND FOG.

(Photos by Capt. Wilson Barker, F.R.S.E., F.R.Met.Soc., &c.)

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be produced in an atmosphere perfectly free from foreign particles by the condensation of aqueous vapour alone; this has been shown by Aitken and Tyndall. In addition to the cooling produced by the mixture of two masses of air of different temperatures, fogs may be produced by the passage of a warm damp current over a cold surface, and also by the passage of saturated air over a warm water surface. The water, being warmer than the air, gives off more vapour than the latter can contain, and thus a fog is produced. Of course no fog can be formed in windy weather, since it is dissipated by the least motion of the air. Mists are similar in character to fogs, but the particles are larger, and they feel wetter. They are more commonly found on parts of hills covered with trees, and near the banks of rivers and marshy places, than elsewhere. A cloud is in reality only an extensive fog or mist existing at a greater altitude, and its formation, as at a mountain top, is due to the condensation of moisture from the warm lower air in passing over it. This has its temperature lowered and is thus forced to deposit part of its contained moisture.

In making observations of meteorological phenomena it is customary to estimate the *amount of cloud* visible in the sky at the time of observation. The ordinary estimation is by tenths, 0 being recorded for a clear blue sky, 10 for one altogether covered by cloud. Variations in estimation as to the amount of cloudiness naturally prevail to a considerable extent, and the same cloud appears of a very different size near the horizon than when higher up in the sky. With regard to the speed of clouds generally much information has been recently gained. The Blue Hill (U.S.A.) Observatory results give an average speed of about 20 miles per hour for stratus clouds at an altitude of about 2,000 feet, whilst for cirro-cumulus at 4 miles high the speed increases to 70 miles per hour, and for very lofty cirrus (5 to 6 miles above the ground) this may amount to as much as 80 miles per hour. It has been asserted that speeds of 250 miles per hour have been observed! (Archibald). For every 1,000 feet of ascent add on about 2 miles an hour to the velocity of motion (Archibald). The speeds are greater in winter, but the average height of clouds are greater in summer than in winter. The observations at Upsala and other places in Europe give less rapid but still large speeds for the upper clouds. Speeds of 19 miles per second for clouds at 4,300 feet, and 38 miles per hour for clouds at 38,000 feet were noticed. These rapid movements of the upper air *may* eventually be utilised in "flying machines" travelling with the wind. The successive cloud layers, which, as we have already said, tend to form at about certain definite levels, coincide with air streams differing from one another in point of velocity, temperature, and humidity, and these must exercise a marked influence on the weather conditions below.

We shall next devote a few lines to the question of the formation of clouds. Every cloud is the visible top of a column of invisible water vapour, sometimes stretching from the ground upwards, and becoming condensed on reaching a colder stratum of air. At every temperature a certain proportion of water vapour may be maintained in the gaseous state, but when this amount is exceeded, or the air is "saturated," the excess is usually condensed, though it has been found that perfectly clear dust-free air may be supersaturated; but when fine particles of solid matter are present condensation takes place round these as nuclei. It has been supposed that sudden rainfalls are due to this condition of vapour saturation, but Mr Aitken has found that the presence of dust is absolutely necessary to the formation of rain. The amount of water in the air rapidly decreases as we go upwards, though cirrus clouds at a height of 50,000 feet have been occasionally noticed, these latter being probably composed of small ice particles or "needles." The shallow stratus, cirro-cumulus, and cirro-stratus clouds are supposed to be due to the mixture of a layer of warm air with an underlying colder stratum. When one current crosses another it raises waves in the latter; the "mackerel sky," and the long rolls of dark cloud following one another at the rear of a storm, with showers and brighter intervals, being examples of such aerial waves. The clouds around mountain-tops are due to the cooling produced by these latter causing condensation of part of the moisture in the air which is rising upwards.

The "table-cloth" over Table Mountain and other hills is formed by the passage of a warm moist current of air over the cold hilltop, whose action condenses part of this moisture. When it passes beyond the mountain the cloud mixes with warmer air, and is once more dissipated, but as fresh air is continually rising, a cloud is almost constantly formed over the mountain, but consists of constantly changing particles of water. The clouds occurring in connection with cyclones are due to the ascent of damp air rising and mixing with the drier atmosphere above.

The literature of cloud prognostics is very extensive, and from all ages the portents and signs of coming weather changes have been discussed with more or less ingenuity by many writers. The remarks of the late Admiral Fitzroy, though given elsewhere, may be here quoted:—

"After fine weather the first signs in the sky of a coming change are usually light streaks, curls, wisps, or mottled patches of white distant clouds, which increase, and are followed by an overcasting of murky vapour that grows into cloudiness. The appearance, more or less oily or watery, as wind or rain may prevail, is an infallible sign. Usually the higher and more distant such clouds seem to be, the more gradual but general the coming change of weather will prove."

Further remarks by the same author with reference to the motions, colours, etc., of cloud forms, are quoted in Mr Inward's valuable "Weather Lore." Some of the descriptions of these phenomena to be found in the Bible show the results of careful observation on the part of the scriptural writers. Many references to cloud phenomena are especially to be found in the book of Job. In Aristophanes' comedy the "Clouds," written as a satire on Socrates and his teaching, "the clouds" are supposed to be the new, hitherto unknown deities introduced by that philosopher to the Grecian world, to replace the gods and goddesses of Olympus. Shakespeare's description of some cloud appearances and changes may be worth quoting here:—

"Sometimes we see a cloud that's dragonish
A vapour sometimes like a bear or lion,
A towered citadel, a pendant rock,
A forked mountain, a blue promontory

With trees upon't that nod unto the world
And mock our eyes with air.
That which is now a horse, even with a thought
The rack dislimns and makes it indistinct
As water is in water."

Of a coming storm he says in the *Tempest*:—

"And another storm brewing;
I hear it sing i' the wind
Yond' same black cloud,
Yond' huge one,
Looks like a foul lumbard
That would shed his liquor . . .
Yond' same cloud cannot chuse
But fall by pailfuls."

The shepherd of Banbury is full of weather wisdom from the appearances of clouds. When they increase, we are told: "If the sky from being clear becomes fretted or spotted all over with bunches of clouds, rain will soon fall." Again, with regard to wind, he says: "If you see a cloud rise against the wind, when that cloud comes up the wind will blow the same way," etc. As signs of a coming storm: "In summer, when wind has been south for two or three days, and it grows very hot, you see clouds rise with great white tops like towers, there will be thunder and rain suddenly. If two such clouds arise, one on either hand, it is time to make haste to shelter." The appearance of cloud hats or "caps" on distant hills, especially when these lie to the south or southwest of the observer, is looked upon as a sure sign of approaching rain. Many such sayings are common in Scotland—

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

the latter being to the south-west of the former.

CHAPTER VIII

THE WINDS — DIRECTION — COMPASS AND TRUE BEARINGS — RELATION TO ISOBARS — BEAUFORT'S SCALE — BUY BALLOT'S LAW — TRADE WINDS—GENERAL CIRCULATION—SPECIAL WINDS : FÖHN, SCIROCCO, BORA, MISTRAL, LAND AND SEA RREEZES — NOTE ON WIND VELOCITIES AND BEAUFORT'S SCALE.

THE wind is a body of air in motion, and this motion being produced by differences of barometric pressure in different directions, it is found that as a general rule the "force" or velocity of its movement is roughly proportional to the closeness of the isobaric curves, being considerable when they are near together, and small when they are wide apart. The direction of the wind is recorded according to the point of the compass *from which* it blows, and it is perhaps advisable in this connection to recollect that the north-seeking end of the magnetic needle does not point exactly towards the true or geographical north, but at present (1911) makes an angle of about 15° to the west with it, for the neighbourhood of London. This "variation" is slowly changing from year to year, at present diminishing, and in about fifty years' time *true* and *magnetic* north will coincide. It is customary to divide the whole circumference of the compass card into thirty-two parts called points, each point making thus an angle of $360^\circ \div 32 = 11\frac{1}{4}^\circ$, with the neighbouring points on either side of it. In practice it is usually sufficient in estimating the direction of the wind to use eight principal points only, N., N.E., E., S.E., S., S.W., W. and N.W. In estimating the closeness of any two isobars, on which the force of the wind depends, we take the slope of the barometric gradient, measured at right angles to the isobar curves, this being the shortest line which can be drawn between them. Gradients are measured by the number of millimetres of *barometric* pressure difference in one geographical degree, or their equivalents in English measure, 1 mm. = 0·04 inch, and 60 nautical miles = length of 1°. According to its intensity the wind is variously designed as *light*, *moderate*, *fresh*, *strong*, *gale*, *storm*, or *hurricane*. The well-known Beaufort's scale is still in very general use. On this system an arbitrary series of numbers, from 0 to 12, "calm" to "hurricane" is taken to estimate approximately the various intensities of wind corresponding to velocities from 0 to 100 miles per hour.

The following numbers give the approximately equivalent velocities of the wind as determined by the British Meteorological Office:—

Wind.	Velocity in miles per hour.	Wind.	Velocity in miles per hour.
0 Calm	3	7 Moderate gale	40
1 Light air	8	8 Fresh ,,	48
2 Slight breeze	13	9 Strong ,,	56
3 Gentle ,,	18	10 Whole ,,	65
4 Moderate ,,	23	11 Storm	75
5 Fresh ,,	28	12 Hurricane	90
6 Strong ,,	34		and upwards.

[*See* also note at end.]

Though, as we have said, the force of the wind varies directly with the closeness of the barometric gradients, yet for any *given* gradient in this country, winds from north and east are stronger than those from the south and west points, by at least one-third of their whole amount. In certain cases of tropical and subtropical winds, such as the "northers" of New Mexico and the "nortes" of Panama, the force of the wind is quite disproportionate to the gradient. There are also some few winds distinctively called "non isobaric," whose origin does not appear to be due to differences of barometric pressure. Since in general, whenever there is a difference of pressure, the air must flow from a region of high pressure towards one where it is low, we see at once that there must be a relation between wind and air pressure. The law expressing this relation is known by the name of Buy Ballot, a Dutch professor who drew attention to its importance. It is commonly enunciated in the following terms:—

> "If you stand with your back to the wind in the Northern Hemisphere, the barometer will be lower on your left hand than on your right. In the Southern Hemisphere, standing with your back to the wind, you will have a lower barometer on your right hand than on your left."

Thus (in our latitudes) if the barometer is higher to the north than to the south, the wind will be east, southerly if the pressure is higher to the east than the west, and so on. Thus in every case in the Northern Hemisphere "whenever we find an area of low readings, the wind moves round it against watch hands, and whenever we find an area of high readings, the wind moves round it with watch hands" (Scott). The converse is the case for the Southern Hemisphere.

Though in our own country we are accustomed to regard the direction of the wind as a symbol for all that is most variable, yet in other regions there is more regularity in the phenomena of its motion. Two main currents may be distinguished, the equatorial warm current northwards and southwards towards either Pole, and the polar cold current from either Pole towards the Equator. The cause of these great atmospheric currents is of course the difference of temperature between the equatorial and polar regions. Air heated in the former regions, becoming lighter, ascends, and its place is taken by colder air flowing in from other parts. Hadley, nearly two hundred years ago, pointed out that a mass of air moving polewards will be deviated towards the east by the effect of the earth's rotation, since it is coming from a region of quicker rotation towards one of slower movement, and conversely the polar currents will be deviated in the opposite direction (or lag behind). His theory was, however, imperfect in that he assumed that only currents moving along the meridian (*i.e.*, due north or due south) are thus affected, but it was shown by Poisson in 1837, that the effect of the earth's rotation on a freely moving mass near its surface, is to cause a deviation to the *right* in the Northern Hemisphere, and to the *left* in the Southern Hemisphere, independently of the direction in which the mass may be moving. Ferrel during 1858 and 1859, developed a theory of atmospheric motions, based on this theorem of Poisson, which he independently discovered. He gave briefly the theory of cyclones, tornadoes, etc., and showed why the law of Buy Ballot is true.

We have said that air currents from the Equator into higher latitudes are deflected by the earth's rotation, and thus in the Northern Hemisphere the south wind becomes a south-west one, and the polar current flowing equatorwards becomes a north-east one. The latter is known as the north-east trade wind, and blows with great persistency over the Northern Atlantic and North Pacific Oceans. In the Southern Hemisphere we have the south-east trade winds. Near the Equator, we have a calm belt occasionally broken by violent storms. The trade-wind zones as well as the intervening belt of calm, shift their position somewhat during the course of the year, being about 10° lower in March than in September. Thus the north-east trade wind blows between latitudes 25° and 3° N. in the spring, but in September its position is between about 35° N. and 10° N. The "calm" and "south-east" trade zones undergo corresponding changes. In Southern Asia and over the Indian Ocean, we find the well-known "monsoons" blowing for one half the year in one direction, and for the other half in the opposite direction. The south-west monsoon blows between May and October over the Northern Indian Ocean, whilst the north-east trade wind blows during the rest of the year.

South of the Equator the south-east trade blows from May to October, and the north-west monsoon "formed from the north-east trade wind drawn across the Equator," blows from October to May.

The following is in a few words the most general account of the circulation of the air, and variation in mean barometric pressure throughout the globe. We have first a zone over the Equator at which the pressure is about 29·8 inches (of mercury), on either side of which there is a belt of higher pressure (about latitude 30° N. and S.), reaching to 30·2 in. Within this area the trade winds blow throughout the year, except over the north part of the Indian Ocean, where in July they blow inwards towards an area of low pressure and high temperature, the "south-west monsoons," whilst in January, the "north-easterly" winds prevail over this region. Further north and south (polewards) of these regions of higher pressure, the winds *in general* blow towards the poles.

Throughout Europe the most frequent wind is the south-western, whilst in Asia and Eastern North America the north-west wind is perhaps more prevalent. On the whole, from Hann's investigations, it may be stated that the warmest winds, the southerly and westerly, produce a mean elevation of temperature in Central Europe of from 2° to 6° above the value it would otherwise have, whilst on the other hand, the northerly and easterly winds produce a lowering of from 5° to 7°, the north-east causing the greater depression. The conditions are otherwise in Asia, the most frequent wind, the north-west, lowering the temperature as much as 4·5°, though on the other hand, the south wind raises it by 10·4°, but is a very rare phenomenon

(Scott). This predominance of the south-westerly winds over Europe is not a general phenomenon, but, speaking generally, " in winter the air flows off the land on to the sea, and in summer it flows off the sea on to the land " (Scott). The latter are the " rain bringers," the former usually dry winds. Thus in our country we find the south and south-west winds are the rainy ones (and warm), the north-east wind is cold and dry. The late James Glaishers, F.R.S., for many years in charge of the meteorological work of Greenwich Observatory, gave the following as the average number of hours per annum that the wind was in each one of the eight principal " points," from the mean of ten years' observations.

The wind was	N.	on	827·2	hours.
,,	N.E.	,,	1018·9	,,
,,	E.	,,	599·4	,,
,,	S.E.	,,	566·4	,,
,,	S.	,,	641·0	,,
,,	S.W.	,,	2737·4	,,
,,	W.	,,	1252·7	,,
,,	N.W.	,,	557·8	,,
,,	Calm	,,	564·0	,,

[*Journal of the Royal Meteorological Society*, vol. i.]

Of various local varieties of wind distinguished by special names, we may refer to the Föhn wind of Switzerland, the " North-Westers " of New Zealand and similar hot currents, the " land and sea " breezes so common in hot countries, but not altogether unknown in our own, the cold "blizzards" and "barbers" of North America, etc. The Föhn wind is a hot current of air which, at first moist, expands in passing upwards on the sides of the mountains, precipitates most of its vapour and becomes compressed and hotter in descending on the opposite sides. The Chinook wind of Canada is of a similar nature, and blowing warm from the Rocky Mountains, helps to raise the temperature of the plains below. In North Greenland a warm south-east wind sometimes blows from the interior mountain regions. A similar origin is to be looked for in the case of the "North-Westers" of New Zealand, the hot winds of South Africa, and of parts of Australia. The dry, parching air of the "Nor'-wester" after a while gives way to the "Southerly buster," bringing coolness and rain in abundance. The "Scirocco" or south-easterly wind of Italy and Sicily has also, perhaps, the character of a dry, hot wind, but there are contradictory accounts of its nature; relief from its scorching action comes with the advent of the northerly "Tramontana." The "Harmattan" of West Africa is a hot east wind, blowing from the desert, and bringing with it clouds of red dust far out into the Atlantic. A similar wind from the desert blowing towards Spain is known in that country as the "leveche," and in Egypt the "khamsin," from the Arabic (for fifty) since it is considered to blow for fifty days.

In North America cold, often snow-bearing winds are sometimes designated by the name of "Barbers" or "Blizzards," and the latter name has been applied by the newspaper press to any cold wind during the winter, accompanied by driving rain, snow, or sleet. The "Mistral" of the South of France, the "Bora" of the Adriatic, and the "Nortes" of Mexico are cold northerly winds, coming at the rear of cyclonic disturbances. The Bora acquires its specially cold, penetrating feeling, coming down from a lofty plateau to lower regions; the Mistral, formerly considered to arise from a sudden cooling of the wind passing over the Pyrenees or the Alps, was shown by Marie Davy and Kaemtz to be due to more remote causes. Whenever it blows in Provence there is a region of high pressure to the east of the Gulf of Lions (Flammarion), and the violence of the wind is due to the shape of the "Pyrenean isthmus."

"Since the general direction of the atmospheric movement extends slightly towards the north-west, the central plateau of the Alps bends the air currents towards the Gulf of Lions. Cooped up between the Alps, the Pyrenees, and the Cevennes, it becomes a kind of 'rapid' over Languedoc, thence arises the high pressure to the north-west of the Cevennes and low pressure over the Mediterranean. From this cause the violence of the north wind in the Rhone valley. The mistral is the driest wind in these regions, because it becomes dried in its passages over the Cevennes, for it is rainy on the north-western slopes."—FLAMMARION.

This wind is the exact opposite to the Föhn. An old couplet says—

> "Le Parlement, le *Mistral* et la Durance,
> Sont les trois fléaux de la Provence,"

thus classing it as one of the three plagues of the land of Troubadours and Trouvères.

A few words on the local winds known as land and sea breezes may fitly conclude this chapter. Most commonly towards noon on coast regions a breeze sets in blowing from the sea towards the land and gradually decreases in the afternoon, dying away at sunset. Towards midnight the air begins to blow in the opposite direction, from the land towards the sea. This action decreases after a while, and by sunrise the air is calm again. The old explanation of this circulation was that the land by day being hotter than the sea gives rise to ascending currents which are replaced by cooler air from the sea, whilst at night the land being cooler than the sea, the air immediately over it, colder and denser, flows outwards till the pressure over sea and land is equalised. This is still given in some text books, but Laughton, Blandford, and others have doubted the validity of this explanation. Mr Blandford considers that when the air over the land is expanded by heat and raised, the upper strata move off towards the cooler sea, and produce increased pressure at some distance from the land. The air flows from this high pressure region towards those positions where the pressure is less, and so we get a sea breeze "setting in from the offing," as Dampier long ago pointed out, not a wind drawn in by suction. By night the action is reversed, and the atmosphere over the land is cooled and contracts; an isobaric slope is thus created, and the upper air slides down from the sea, sinking over the land and pushing out as the land breeze (Scott). The surface land breeze of evening is often accompanied by squalls of considerable strength. As was to be expected, the sea breeze is generally moist, the land breeze dry, and sometimes deleterious in its effects.

Such breezes are light on a low flat island or coast, but when there is a range of mountains not far from the sea, these winds are sometimes much stronger. The sea breeze of Jamaica owing to the proximity of the Blue "Mountains," is often very powerful.

Note on Wind Velocities.—The velocities corresponding to the numbers of the Beaufort scale, are sometimes calculated by an approximate formula, $V=1{\cdot}87\sqrt{B^3}$, or by the simpler $V+3=5B$, where V is the wind velocity in miles per hour, B, the numbers

1, 2, 3, etc., of the Beaufort scale. Thus from the second formula we have the corresponding numbers,

Nos. Beaufort scale	1	2	3	4	5	6
,, Wind velocity ($V+3=5B$)	2	7	12	17	22	27
From the first formula ($V=1{\cdot}87\sqrt{B^3}$)	2	5	10	15	21	28
Old values	(0=3)	(1=8)	(2=13)	(3=18)	(4=23)	(5=28)

the numbers agreeing sufficiently well calculated by either form, but (1) on this scale corresponds more closely to (0) on the older form (2) to (1), etc., as will be seen by the figures in brackets. (*See* also the introduction by Dr W. N. Shaw, to a recent publication of the Meteorological Office by Commander Hepworth, on "Trade Winds in the Atlantic," etc., 1910).

CHAPTER IX

MISCELLANEOUS PHENOMENA—SNOW—HAIL—DOVE'S THEORY—VOLTA'S THEORY — DEW — FOG—MIST—RAINBOWS—HALOS—"CORONÆ"—THE MIRAGE—BLUE OF THE SKY—TINTS OF SUNRISE AND SUNSET—DUST.

OUR earth, seven-tenths of whose surface is covered by water, is surrounded by an envelope of air known as the atmosphere, which presses on all bodies at the level of its surface with a pressure of nearly 15 lbs. per square inch, and extends to an unknown height above. Its density is greatest at the earth's surface, and rapidly decreases as we go upwards, but no certain limits can be assigned beyond which we can positively assert that there is no atmosphere at all, though at a height not greatly exceeding 100 miles from the ground the quantity of air must be very small indeed. This atmosphere is composed of a mixture of several gases—oxygen, nitrogen, argon, and carbon dioxide—with a variable quantity of water vapour, small traces of nitric acid, ammonia, etc., and minute quantities of almost all other substances. Were the whole atmosphere of uniform density, its height would be only about 5 miles, and this height (26,000 feet) is sometimes called the height of the *homogeneous* atmosphere, and would produce a pressure at the earth's surface equal to the actually existing pressure. This air pressure on every square inch is equal to that produced by the weight of a column of mercury 30 inches high and 1 square inch cross section (mean height of the barometer). Stated in terms of the C.G.S. system (in which the *unit* of length is 1 *centimetre*, the unit of mass is the *gramme*, and the *second* the unit of time) the air pressure on each square centimetre is equal to that of a column of mercury 76 cm. high and 1 sq. cm. in cross-section. This pressure is known as 1 *atmosphere* of pressure, and expressed in English measure it is equal to 14·7 lbs. per square inch. The pressure becomes less and less the higher we go up. Thus Pascal found that the pressure diminished in ascending the Puy de Dôme by about 7 inches (of mercury), from 30 inches at the bottom to 26 inches at the top (*see* also Introductory chapter).

The amount of aqueous vapour contained in the air varies considerably from time to time. At any given temperature, however, there is a maximum amount which can remain in the gaseous condition, and when the air contains this amount it is said to be saturated. The amount necessary for saturation varies with the temperature, being greater as the temperature is higher and less when the temperature is lower. A rise of temperature in a quantity of saturated air thus enables it to maintain an increased quantity of water vapour within it, whilst a fall of temperature causes part of its moisture to be deposited in the form of rain (or dew). A mixture of two masses of air at different temperatures, more especially if the warmer air is saturated, will in general cause a condensation of some part of the contained moisture, though when saturated cool air is mixed with unsaturated warmer air, condensation need not occur. This is illustrated by the well-known example:—"If we open the door of a laundry on a cold day a fog instantly forms. If we open the door of an ice-house on a warm day, no fog appears." The former is a case of the mixture of a saturated mass of warm air with colder unsaturated air; the latter is a mixture of saturated cold air with warmer unsaturated air.

Air coming from regions whence it has derived much moisture, as winds blowing in from the sea and rising in currents over the tops of hills, etc., is at first saturated, and being chilled by expansion and contact with the colder land surfaces, deposits most of its moisture in the form of rain. Thus the south-westerly and westerly winds, arriving first on our western coasts, come nearly saturated with moisture, which they have acquired by blowing over extensive surfaces of ocean; coming to the hilly western counties they lose much of this moisture, hence the heavy rainfall of those regions, though sufficient remains to make the south-west wind a rainy one everywhere in Britain.

Snow is merely the solid form of rain, which takes the place of the latter whenever the temperature of the surrounding air is at or below the freezing-point of water. It differs from ice in being opaque instead of transparent; this is due to the entanglement of air bubbles, etc. It is often considered that the formation of snow takes place directly from the cooled vapour without passing through an intermediate liquid condition. Snow falls in flakes, whose size varies considerably, and these flakes are found to be made up of crystalline figures of definite symmetrical shapes, having the general "hexagonal" character, six-pointed stars, snow flowers (frequently with a well-marked centre), or hexagonal plates. Whatever the variety of their forms, the angles made by adjacent faces or by the rays of the "stars" have a definite relation to one another, being either 60° or small multiples or sub-multiples of that angle. Being much less dense than rain a fall of snow occupies much greater space than an equivalent amount of rainfall; as a rough rule it has been said that one *foot* of snow is equivalent to one *inch* of rain, but snow is more conveniently measured by thawing whatever collects in the rain gauge, either by adding a measured volume of hot water, or by directly warming and melting the snow itself (a much slower process). Snow, though solid, evaporates slowly, and may thus disappear on a fine sunshiny day without thawing, just as it is supposed to be formed without passing through the intermediate liquid condition.

Hail is allied to snow in character, being also "frozen rain," but is denser and more compact. It is customary to distinguish two kinds: soft hail or "graupel," and true hail (Scott). It is probably due to the freezing of raindrops in their passage through strata of air colder than those in which they were formed. Dove's theory was that hailstorms are whirlwinds, whose axis is rather horizontal than vertical, as is commonly the case with other forms. The growing hailstones are swept round and round from hot to colder strata of air alternately, water collects on them in the warm strata and is frozen in the colder. After a time, by their weight, they fall to the ground. Volta, from the fact that hail often falls during a thunderstorm, and is associated with disturbances of the electrical equilibrium, propounded a singular theory. He supposed that two layers of cloud, one above the other, charged with opposite kinds of electrification, kept the hailstones continually moving up and down by alternate attraction and repulsion, and devised an experiment called "electric hail" to illustrate this. Two metal plates placed one over the other are taken, the upper one is connected with the conductor of an electrical (frictional) machine, the lower one put to "earth." If a number of pith balls are placed on the under plate, when the machine is set working, the balls fly rapidly to and fro between the plates.

Of the two kinds of hail, soft hail is composed of small, rounded, soft pellets and commonly falls in dry weather. This kind is called "graupel" in Germany. The other kind, or true hail, is composed of larger, irregular, more or less concentric layers of hard and soft ice, occasionally showing traces of crystalline structure, whose form resembles that of crystals of calc-spar.

Very large hailstones have been known to fall from time to time. It is recorded that in 1697 Robert Taylor, in Hertfordshire, found hailstones 14 inches in circumference. In tropical countries, and even in certain parts of Europe, much damage is done to vineyards, standing crops, etc., by their impact, and hail insurance is a care for the prudent farmer who does not wish to have the fruits of his labour wasted by a storm. Flammarion relates that the hailstorm of 13th July 1788 which passed over Northern France ravaged 1,039 parishes, and did damage to an amount estimated at 24,690,000 francs (£990,000 nearly). The largest hailstones weighed 250 grammes (9 ozs.), but it has been asserted that at times masses weighing two or three times as much have been picked up.

Stories of stones weighing pounds, or even as large as an elephant, may be disregarded.

Dew is a phenomenon whose appearance seemed very mysterious in early days, and fanciful theories as to its cause were held without any serious grounds. Its explanation was very beautifully given by the late Dr Wells, whose well-known essay is often instanced as a model of the "inductive method." The air, as we know, always contains more or less moisture in suspension in the state of gas, the possible amount that can be contained varying with its temperature, being greater at higher than at lower temperatures. The method by which we "dry" things, *i.e.*, cause their moisture to be evaporated into the surrounding air, depends upon this, we *warm* them. At any temperature the air can contain so much moisture and no more, and when this maximum amount is present, it is said to be *saturated*, and at the temperature of the "dew point." A fall of temperature, as by contact with colder bodies, then causes some of this moisture to be deposited in the form of drops of "dew," since the air, containing its full amount of moisture for the higher temperature, which exceeds the *possible* amount at the lower, part of this moisture must now take the liquid form, since at every temperature a definite proportion of vapour only can be retained. On a fine sunny day evaporation goes on, and the air takes up much moisture. During the evening the temperature falls, more heat being radiated from the ground than is received by the latter from the now declining sun. If the sky be clear, this radiated heat rapidly passes out into space, but if, on the other hand, the sky be cloudy, then much of the heat will be reflected back again. In the former case the ground temperature will fall quickly, in the latter more slowly. The air in contact with the ground will fall to the same temperature as the latter, and if it contain much moisture it will soon reach the dew point, after which part of its vapour will condense. This will be deposited first on those substances which are the best conductors and radiators—grass, leaves, metals—whilst on badly conducting substances, such as sand, gravel, glass, etc., little or no dew will be found. In windy weather, owing to the motion of the air, any given portion does not long remain in contact with the same ground, so that it is not so soon cooled sufficiently and less dew is deposited.

If the temperature of the dew point is below the freezing-point of water, instead of dew we have hoar-frost, which is *not* frozen dew, but water deposited in the solid form (Scott). At times the frost figures seen on trees, twigs, and window-panes are of beautiful forms, not unlike the snow crystals already alluded to.

It is stated that in some of the forests of tropical America the tops of the trees, by their cooling action, condense the moisture so much that a traveller entering finds apparently a heavy shower of rain falling whilst the sky overhead is perfectly clear (Humboldt). It has been estimated by Mr Dines that the average annual deposit of dew on the surface of the ground is about equal to 1·5 inches of rain.

Owing to the fact of radiation being necessary for the formation of dew, its presence is an incidental sign of fine settled weather, though hoar-frosts are said to indicate rain. Thus:—

> "When the frost gets into the air, it will rain";

also

> "If hoar-frost come on mornings twain,
> The third day surely will have rain."

But too much reliance need not be placed on such sayings.

Fog is a phenomenon with which we in this country are only too familiar. Though to be met with at times almost anywhere, fogs are especially prevalent in river valleys and low-lying situations. Essentially the only difference between a cloud and a fog is that the former is formed in the atmosphere at some distance above the ground, whilst the latter is usually close to the earth's surface. The visible "steam" from a kettle is of exactly similar constitution. Water vapour or true steam is completely transparent and perfectly invisible, but in condensing it at first usually assumes the form of excessively minute drops or particles, a number of which collect together into a cloud. Mr Aitken has shown that no fog or cloud can be produced unless there exist some solid nucleus, dust or other substance, round which the water particles may collect, and that condensation of water vapour in perfectly *dust free* air produces no cloud. After this condensation has taken place it will depend upon other circumstances as to what will next happen. Sometimes these droplets coalesce into raindrops, at other times hailstones are formed, whilst again the cloud or fog often retains its first form for a long time without much change.

Fogs may arise in various ways. A mixture of two masses of air at different temperatures, giving a resultant temperature lower than is necessary to retain the whole of its moisture in the gaseous condition, part of this passes into the "cloud" form. A warm, damp current of air flowing over a chilled surface, over the tops of mountains, or over a cold ocean current also gives rise to a fog. Over rivers the amount of evaporation is considerable, and consequently the air is usually saturated. This air, on the smallest cooling, loses some of its moisture, and thus arise the mists and fogs often found near rivers and marshes; especially in winter time, when the water is usually warmer than the surrounding air. Of a somewhat different character are the sea-fogs of summer, common on coast regions. The air over the sea is saturated with moisture from evaporation of the water of the latter, and when it is chilled by contact with colder air a fog is the consequence. "Radiation fogs" found in valleys and damp meadows in the evenings are thus explained. The air near the ground is saturated with moisture, and colder than that immediately above it. Over level surfaces there will be no mixture of air, the colder stratum underlying the warmer, but in valleys and depressions some of the colder air of the upper ground will flow down and mix with the air below, whence results a condensation of moisture and formation of a fog, often very sharply defined, which disappears in the morning so soon as the air is warmed sufficiently by the sun's rays to again take up this moisture.

There is but little difference between mist and fog, except that in the former the particles are somewhat larger, and that the whole appearance is much damper, dry fogs being known, but dry mists never. Mists frequently appear over forests, marshy places, and on hillsides, especially where these are covered by trees and lofty herbage.

The *rainbow* is an optical phenomenon familiar to all, whose general explanation was first given by Sir Isaac Newton, though a partial account, satisfactory so far as it went, was offered by the famous De Dominis, Archbishop of Spalatro, nearly a century before Newton's time. Sometimes one bow is seen, sometimes two, each of these presenting the well-known colours "of the rainbow," but in the reverse order. When only one bow is seen, the red arch is above and the violet below. The second and fainter bow is seen outside the primary, and in it the order of the colours is reversed, the violet being outermost and the red innermost. Between the two bows the sky is usually dark. These bows are produced by the reflection and refraction of the sun's rays by the drops of water forming the cloud against which it is seen. Sunlight (white) falling on the drops of water passes partly inside, and is partly reflected. The portion passing inwards is *refracted* (*i.e.*, its direction changed), but this refraction differs for the different kinds of radiation of which white light is composed. The latter contains rays of many kinds, those affecting the eye, when *separately seen*, causing the appearances known as red, yellow, green, blue, etc., their combined effect producing the sensation of white light. Each of these colours is differently refracted (or bent) in passing from one medium to another (*e.g.*, from air to water), and in consequence the separate rays of white light are *dispersed* or spread out into a coloured band. The red is least deviated from its original cause, or is least *refrangible*, whilst violet is most deviated or most refrangible.

The primary rainbow is formed of rays which have undergone refraction and *one* internal reflection. The angular radius of the red bow is 42° 2′, that of the violet 40° 17′, the intermediate colours being formed between these limits; the whole bow being seen nearly opposite to the sun's position in the sky. The secondary bow is formed by rays which have undergone *two* internal reflections.[1] In this the angular radius of the red bow is 50° 58′, that of the violet 54° 9′, the latter thus being the outermost. Owing to loss of light in reflection, etc., this bow is considerably fainter than the other. Rays which emerge parallel after three, four, and five internal reflections form the third, fourth, and fifth rainbows, but of these the third and fourth are formed in the part of the sky near the sun and cannot be seen, whilst the fifth, though it is formed in the opposite part of the sky, is so faint, after the number of reflections it has undergone, that it is scarcely, if ever, visible. When a rainbow is seen near sunrise or sunset it forms a complete semicircle, but usually only a smaller part of a circle is seen, no rainbow being produced when the sun's altitude is greater than about 42°.

Lunar rainbows are also sometimes seen, but

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[1] In each case the rays suffer *refraction,* both in passing into and in coming out of the raindrops; but the primary rainbow is formed of rays which have undergone *one* internal reflection, the secondary of rays which have been twice internally reflected, and which emerge in *nearly parallel* directions.

owing to their faintness the colours cannot usually be distinguished. When the sun is shining upon the spray from a waterfall or fountain, an observer, with his back to the former, may sometimes see a complete circle of colour. Owing to the fact that the sun is not a mere luminous point, but has an apparent magnitude to the eye, the colours of the rainbow are not pure, but somewhat mixed. When the sun shines through a thin cloud the rainbow is almost white, owing to this mixing of colours going on to a still greater degree.

The large circular rings, called "halos," which are often seen round the moon, but less often round the sun, are due to refraction through, and reflection by the minute snow and ice crystals in the upper air, which compose a cirrus cloud.

They are usually colourless, faint coloration being only occasionally observed, and should be distinguished from the smaller rings more properly known as "coronæ." Most commonly two circles are seen, one having an angular radius of about 22°, the other a radius of 46°, the sun (or moon) being at the centre of these circles. In addition, other circles are sometimes seen, intersecting with the primary circles, and spots of more brilliant light, usually reddish or yellowish, seen to right or the left of the sun's place at about the same angular distance of 22°, which are known as *parhelia*, "mock suns," or "mock moons," *paraselenæ.* All these phenomena are more common in high latitudes than in our own, and during winter rather than summer, as was to be expected from their production by the refraction of light through ice crystals. The appearance of a halo is a very certain sign of unsettled, stormy weather, but the phenomenon is of much less frequent occurrence than that of a corona.

The latter is a coloured ring, or series of rings, often seen round the moon when the sky is covered with much cloud, but its visible appearance round the sun is much more rare, being usually too faint to be detected.[1] The colours of this corona are arranged in the same order as those of the rainbow, violet inside and red outside, but they are usually faint and much less pure. When several rings are seen the innermost one will have a diameter of about 3° or so, the next will be about double this, and the third three times that of the first.

These phenomena are due to "diffraction," or bending of the rays of light by a number of minute particles (the water-drops forming the cloud) of more or less nearly equal size. The diameter of the corona depends upon the size of these droplets and varies inversely therewith, growing smaller when these are increasing

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[1] This optical effect, or corona, of course, is in no way connected with the true solar Corona only seen at the times of a total eclipse. It is somewhat unfortunate that the same name should be used for two so distinct phenomena.

in size and larger when they are decreasing. Thus it is sometimes possible, by watching the change in size of a corona, to infer whether the coming weather is likely to be rainy, or the reverse. When the corona is getting smaller the water particles are uniting and will sooner or later be condensed and precipitated in the form of rain; when the diameter of the corona is increasing, the particles are getting smaller and evaporating. This appearance has been artificially reproduced by Frauenhofer and others. By looking at a luminous object through a glass covered with fine grains, such as those of lycopodium powder, a number of luminous rings will be seen surrounding the object; and an instrument called the eriometer was invented by Dr Thomas Young to measure the diameter of very small objects by means of the size of the rings produced by them round luminous objects, the radii of these rings being inversely proportional to the diameter of these small particles.

Similar appearances may be seen by looking through the meshes of a fine handkerchief at a gas lamp, or through a dimmed spectacle glass on a wet evening!

In Arctic Regions coloured circles of light are sometimes seen round the shadows of the observer's head, or other objects.

The mirage is an optical phenomenon, more common in hot countries than in temperate regions, though it has been often observed by Scoresby and others in high latitudes also.

The observer sometimes sees the inverted image of distant objects and the sky, reflected from the ground as from a lake. In hot, sandy districts the lower strata of air are sometimes so heated that up to the height of a few feet the density is less below than above. Rays of light from distant objects entering these layers of rarefied air obliquely downwards become bent upwards more and more till they fall on a stratum where, instead of being refracted, they suffer *total internal reflection.* Thus they will be bent upwards more and more after passing through the denser layers above, and will reach the eye as if they came from a point as far below the reflecting layer as the objects of which they are images are above it. Sometimes an object is thus seen inverted, whilst other rays which do not pass down into the reflecting layer enable the observer to see it in the upright position, the combination thus seeming like object and image reflected in a lake of calm water.

A similar mirage may sometimes be seen across lakes on tranquil autumn evenings. Here it is the water that heats the lower layers of air, and thus renders them "totally reflecting" (Stewart). Sometimes in the Arctic Regions inverted images of ships are seen in the air, at a time when they are too far away to be directly seen.

It is recorded that Scoresby once observed the image of his father's ship in the air at a time when she was more than 30 miles off. The effect in this case is due to the cooling of the lower air. The rays passing obliquely upwards from the objects into the rarer layers above are more and more bent downwards until they suffer total reflection, and the object is seen apparently up in the air at a great distance. Some years ago, at Dover, ships close in to the French coast were thus distinctly seen from the English side of the Straits (Stewart).

The phenomena of *looming*, the abnormal elevation of distant objects, inverted images seen above the objects, etc., are all due to optical effects of a similar kind. It has been elsewhere mentioned that the blue colour of the sky is probably due to the scattering of light from small suspended particles in the air.

Tyndall supposed that these might be minute water particles, whilst Lord Rayleigh has suggested that fine salt particles, meteoric dust, etc., and even the oxygen of the atmosphere, may be effective in producing this coloration.

The red colour of the sun and moon near rising and setting (and also during foggy weather), the wondrous tints of the clouds at dawn and sunset, are also due to selective absorption and diffraction. Sunlight, composed of all the "colours of the rainbow," is more or less absorbed in passing through the atmosphere, the vapours and dust particles of which exert a much greater action than the pure gases. This action is greater upon the shorter blue and violet rays than on the longer (red and yellow) ones, and most of the absorbent particles are found in the lower layers of the air. Thus sunlight which has travelled through a considerable thickness of the atmosphere will lose a greater proportion of its blue and violet rays than of the longer ones, and consequently these latter predominating, the remaining light will be yellowish or reddish. The late Professor Langley was of opinion that if we could ascend above the atmosphere, the sun would be seen as "blue" or bluish (more nearly like the colour of the electric light) rather than white, as we ordinarily see him.

An extra thickness, as at sunrise and sunset, and an unusual amount of dust and other impurities in the air (as in a November or January fog in London), removes almost all the other rays and leaves the sun only visible as a fiery red ball.

The cloud colours are similarly due to selective "sifting," as it were; the shorter rays being absorbed, the longer more or less reflected. When sunlight falls upon the surfaces of the upper clouds, the violet and blue rays are absorbed, but much of the yellow and red is reflected, and reaches our eyes. The eruption of Krakatoa in 1883 throwing an enormous mass of matter into the air, dust particles probably travelling for thousands of miles, and remaining many months in the atmosphere before subsiding, it was to the presence of these particles that the brilliant sunsets experienced at various places during 1883 and 1884 was attributed, though as brilliant cloud effects have been observed at other times also. Mr John Aitken, to whom is due the recognition of the importance of dust in Nature, and who, more fitly perhaps than Ruskin, may be considered the founder of the "Ethics of Dust," showed that minute motes or particles are everywhere present, even in the purest and clearest air remote from towns. These minute particles catching and scattering the sunlight, are the agents by which the atmosphere is illuminated, and if the air were free from them, the sky would be seen perfectly black except where the sun or a star was to be found. He considers the blue of the sky to be due to the scattering action of the dust motes in the higher layers, as also the red tints of sunrise and sunset, and the twilight generally.

CHAPTER X

METHODS OF HEAT TRANSFERENCE — OCEAN CURRENTS — THE GULF STREAM—INFLUENCE ON TEMPERATURE AND OTHER WEATHER CONDITIONS—THEORIES AS TO ITS ORIGIN, ETC.—THE HUMBOLDT OR PERUVIAN CURRENT — COOLING EFFECT — CHINA CURRENT— "KURO SIWO" — CURRENTS OF THE INDIAN OCEAN — AGULHAS CURRENT—POLAR CURRENTS—IDEAS AS TO THEIR CAUSES.

THERE are three great methods whereby heat is conveyed from a body radiating it, to others—radiation, conduction, and convection. Radiant heat is a form of energy, differing only from light in the greater length of its waves, and travels, apparently without the help of a material medium (unless the ether be such), from the sun and stars throughout space to our earth. Its course undergoes a slight refraction or change of direction by passing through the atmosphere, and it is to a small extent *absorbed* or converted into *sensible* heat by this medium, but a large part of it reaches the lower regions and warms the ground and the waters of the seas. By a much slower process some of this heat received by the ground is *conducted* downwards, and in other directions, in the same way that a poker with one end plunged in a flame gets gradually hot all through. This process is called *conduction,* and is *almost* confined to solids. The effect of heat when absorbed being in general to cause an expansion of the substances receiving it, they become specifically lighter. The particles of a solid are held together by cohesion, but those of a fluid, liquid or gas, are not thus restrained. Consequently, heated fluid particles, if the heat be first imparted from below, become lighter and rise, their place being taken by the heavier particles above, which sink, and thus ascending currents of hot particles and descending ones of colder are set up. This process is known as *convection,* being a bodily transference of particles carrying heat with them, part of which is imparted by radiation and sometimes by conduction to other substances with which they come in contact.

Thus arise *convection currents,* of which the ocean currents, and the great air currents, equatorial and polar, etc., are well-known examples on the largest scale.

The motions of water through the ocean in definite directions being an actual transference of the particles of the fluid must be distinguished from tidal and other waves, which, though setting up motions which travel sometimes all round the globe, do not usually cause any bodily transference of matter, but merely a slow up and down motion of individual particles. The particles of water rise and fall to a greater or less degree, but do not change their mean position; it is merely the transference of the wave form that takes place, so that we may regard a *wave* as being a means for the motion of energy from point to point, whilst a *current* transfers matter also. It sometimes happens, as at the mouth of large rivers, that the small oscillatory *tidal* motion of the ocean is transferred into a bodily motion of large masses of liquid, which travel upwards towards the source, and then down again periodically (usually twice in every day), thus the tidal wave in this case becomes a *current*.

The tides of the ocean are of extreme importance in navigation and many other ways, but their detailed study scarcely belongs to our subject. On the other hand, the tides of the atmosphere, or at least that small portion of it which has alone hitherto been carefully studied or accessible to our study, are, so far as known, small and insignificant, in most cases masked by far larger irregular forms of motion, though in tropical regions the daily "barometric tide" due to the sun, and no doubt to some extent the moon also, is a sufficiently marked phenomenon, at least, during settled weather, any interruption to which is a sure sign of a change. Indeed, so regular is the daily rise and fall of the barometer (not amounting anywhere to more than 0·12 inch), that it is said that in India the time of day can be told by the reading of the barometer.

But the importance of ocean currents is such that some account of the principal of these must now be given, as well as their effect upon climatic conditions.

Some currents, such as the Gulf Stream, the best known of all, convey heat from the equatorial regions towards the extra-tropical latitudes; others, such as the Humboldt current of the Southern Pacific, help to render the climate of the regions towards which they blow more foggy and colder than would otherwise be the case.

The words of Maury ("Physical Geography of the Sea") may fittingly serve as an introduction:—

> "There is a river in the ocean. In the severest droughts it never fails, and in the mightiest floods it never overflows. Its banks and its bottoms are of cold water, whilst its current is of warm. The Gulf of Mexico is its fountain, and its mouth is in the Arctic Seas. It is the Gulf Stream. There is in the world no other such majestic flow of waters. Its current is more rapid than the Mississippi or the Amazon, and its volume more than a thousand times greater."

Circulating thus from the Gulf of Mexico, it passes out into the Atlantic Ocean; it pours out through the Straits of Florida, as a stream of hot water, whose temperature is at least 10° above that of the surrounding ocean through which it flows, at a rate of over 6 feet per second, having a width of about 30 miles when passing the Straits of Bemini. It gets gradually wider as it flows northwards (its depth off Cape Hatteras being about 700 feet), till off the coast of Newfoundland it has a width of 320 miles, after travelling nearly 2,000 miles from the Straits of Florida, its speed meanwhile having fallen off to one-third of its original value. It flows thence north-eastwards towards the Azores, where it divides, one portion going past these islands, and to the north of Norway; the other part bending more to the right, passing the coast of Portugal, and going southwards towards the Cape Verde Islands, whence it runs back almost due westward to the West Indies.

From the Straits of Bemini the course of the Gulf Stream is as nearly as possible the arc of a great circle, very nearly the course that would be taken by a cannon-ball, could it be shot from these Straits to the British Islands (Maury). The waters are of an intensely blue colour, whose temperature on a winter's day, off Cape Hatteras, and even as high as the Grand Banks of Newfoundland, in mid-ocean, is sometimes 20° or even 30° above that of the ocean near by. It flows through the Straits of Bemini with a temperature exceeding 80° F.; but this falls off as it proceeds northwards, yet it everywhere exerts a beneficial influence on the neighbouring lands.

As an instance of the Gulf Stream influence upon British climate, and the contrast between our temperatures and those of regions where its action is not felt, may be mentioned the opposite cases of the harbours of Liverpool and St. John's, Newfoundland, instanced by the late Mr Redfield.

"The latitude of St. John's (48° N.), is 5° less than that of Liverpool (53° N.), but whilst in 1831 the harbour of the former was closed with ice as late as the month of June, who ever heard of the port of Liverpool being closed with ice even in the dead of winter?"

It is even stated that the ponds in the Orkneys (latitude 60°) are not frozen in winter (Scott); another instance of the "grand heating apparatus" of this "stream."

Not only does the Gulf Stream convey heat to regions where the sun shines less powerfully than it does in the Gulf of Mexico, but by its carrying off the heated waters northwards, it gives place to cooler currents through the Caribbean Sea, these helping to moderate the excessive heat of the countries around. Different estimates of the effect of the Gulf Stream have been made by the late Dr Croll, the late Rev. Professor Haughton, and others. Dr Croll finds that the Gulf Stream conveys into the Atlantic about one-fifth of the "total heat" found in it, but this seems too extravagant an estimate. Taking the temperature of the surface at 56° F., and the "absolute zero" as $-460°$ F., we have $56° + 460° = 516°$, one-fifth of which is 103°, and if we subtract this from 56°, we have $56 - 103 = -47°$ F., or nearly 80° below the freezing-point of water, as the temperature of the Atlantic, apart from the influence of the Gulf Stream. Mr Scott's calculation ("Meteorology," p. 301), giving $-3°$ as the resulting temperature, though too high, unless we assume with him the temperature of "space" to be more than 200° F. above the absolute zero ($-239°$), shows this sufficiently well, but the result is yet more striking with the figures I have taken. On the other hand, Dr Haughton found a much smaller effect, a scarcely perceptible action during the summer months, *perhaps a slight lowering*, but a very sensible increase of temperature for the winter, amounting for latitude 60°, to about 37·0° F., and over 40° F. for latitude 70°, its value for our latitudes (50°) being 21·7°.

The motion of the current off our own islands is very slow, estimated at not more than 1 inch or so per second, but evidence of this motion is said to be afforded by the occasional discovery of West Indian fruits, beans, etc., on the western coasts, thrown up by the waters of the ocean. The time required by the waters of the Gulf Stream to flow from Florida to Western Europe has been estimated at between five and six months, and the whole time required for a particle to make a complete circulation back again into the Gulf of Mexico after coming to Europe would be about two years and ten months (Scott).

With regard to the influence of the Gulf Stream upon climate, we have already indicated some of the more prominent thermal effects, about whose *magnitude*, however, some difference prevails, some recent authorities perhaps being as much inclined to *underrate* these as others formerly *overrated* them. The dampness of Ireland in particular, and the British Islands in general, as compared with the climate of other parts of Western Europe, may be partly set down to its credit, but only so far as the rain of the south-westerly winds is produced through its agency. With regard to its influence upon the meteorology of the ocean through which it flows, a few remarks must here suffice. The Gulf Stream is the great "weather-breeder" of the North Atlantic (Maury). Various gales of wind sweep along it from time to time, and "sailors dread storms in the Gulf Stream more than they do in any other part of the ocean." The stream current flowing in one direction whilst the wind is blowing in another, creates a very disturbed state of the water. Many of the most destructive storms appear to owe their origin to the irregularity between the temperatures of the Gulf Stream and those of the neighbouring air and water. Another remarkable directive action has been attributed to this current, whose *general* effect is so beneficial. Storms of greater or less magnitude that take their rise on the African coast have been shown to make straight for the Gulf Stream; on joining it they have then changed their course, travelled with the current, and recrossed the Atlantic, carrying disaster in their train.

Many theories have been propounded from time to time as to the cause of this great ocean current. Early writers, regardless of the fact that the volume of the Gulf Stream many times exceeds that of any river, supposed that the Mississippi River, flowing into the Gulf of Mexico, became the "father" of the Gulf Stream; but this was conclusively disproved by the enormous volume of the latter, and the fact that its water is salt, whilst that of the river, its supposed origin, is fresh. Franklin's view was that the Gulf Stream is the escaping of the waters that have been forced into the Caribbean Sea by the trade winds, and that it is the pressure of those winds upon the water which forces up into that sea a "head" for the stream. This view seems the most probable one as to the origin of this current, but objections have been raised by Maury and others as to the *adequacy* of the wind pressure to alone give the necessary initial velocity, though they do not deny that this must be an important factor, combined with other agencies; amongst which the late Commander Maury was inclined to consider the difference of saltness prevailing between the equatorial and polar seas, on the one hand, the Caribbean Sea and the Gulf of Mexico, "with their waters of brine," on the the other, the great polar basin, the Baltic, and North Sea, with their little more than brackish waters. Another cause of circulation is the difference of temperature between the inter-tropical and polar seas.

"In one set of these sea-basins the water is heavy, in the other it is light. Between them the ocean intervenes, but water is bound to seek and to maintain its level, and here, therefore, we unmask one of the agents concerned in causing the Gulf Stream."—MAURY.

Amongst other currents whose influence on the climate of the regions towards which they flow, though less marked than the Gulf Stream, is considerable, may be mentioned the well-known Humboldt current of the South Pacific, so named from the "great and good man" who was the first to make it known, the polar current of the North Atlantic, the warm current of the Indian Ocean, flowing south midway between Africa and Australia, and the China "Gulf Stream" of the Northern Pacific, whose course is not quite so well known, the Agulhas current of the Indian Ocean, etc.

The Humboldt current flows northwards from the South Pacific or the Southern Ocean, past the western coasts of Chili and Peru, bringing up colder water than that of the surrounding sea, almost as far as the Equator. Its effect is most preceptible, however, between 20° and 30° S. latitude. To a certain extent it mitigates the otherwise rainless climate of Peru and renders the latter much more salubrious than would else be the case.

"The climate of this inter-tropical republic is thus made one of the most remarkable in the world; the Andes with their snowcaps on the one side of the narrow slopes, and the current from the Antarctic regions on the other, cause the temperature to be such that cloth clothes are seldom felt as oppressive during any time of the year, especially after nightfall."—MAURY.

Between the region of this current and the Equator is an area known as the "desolate region." Few birds are ever found here; the sea-bird that joins the ship as she clears Australia will, it is said, follow her to this region and then disappear; "even the chirp of the stormy petrel ceases to be heard here," the whale is seldom seen, and the albatross and Cape pigeon are no longer found. There appears to be a warm current flowing from the inter-tropical regions of the Pacific, midway between the American coast and the shore lines of Australia, whilst further to the northward is to be found the China current, or "Gulf Stream of the Pacific," as it is sometimes called, or the Kuro-siwo of the Japanese. This current of warm water is of considerably greater volume than that of its namesake in the Atlantic, and serves to mitigate the severity of the winter on the shores of Alacka and British Columbia. As with the Gulf Stream, there is a counter-current of cold water between it and the shore (Maury).

Thus a parallel may be drawn between the opposite hemispheres, the climates of the Asiatic coast of the Pacific corresponding with those of North America along the Atlantic, China answering to the United States, the Philippines to Bermuda, Japan to Newfoundland, whilst Columbia, Washington, and Vancouver correspond to Western Europe and the British Islands.

"The climate of California (State)," says Maury, "resembles that of Spain; the sandy plains and rainless regions of Lower California remind one of Africa, with its deserts between the same parallels, etc. The North Pacific, like the North Atlantic, is enveloped, where these warm waters go, with mists and fogs. . . . The Aleutian Isles are almost as renowned for fogs and mists as are the Grand Banks of Newfoundland."

The South Pacific current, flowing from the eastward of New Guinea south towards Australia and thence again eastward, appears to have been first detected by the late Commander Maury, who also suspected the existence of smaller equatorial currents in this ocean. Both in the North and South Atlantic there are to be found regions where little or no current is perceptible, and where, as a consequence, drift-wood, sea-weed, and other *débris* collect. This region in the Atlantic is known as the "Sargasso Sea," from the quantity of gulf-weed, *sargassum bacciferum*, a vegetable growth found covering many leagues of the surface of the ocean. The similar region in the South Atlantic contains less weed, but is still known by analogy as the *Southern* Sargasso Sea, whilst Maury and others have asserted the existence of a Sargasso Sea in the Pacific also.

The currents of the Indian Ocean are governed mainly by the prevailing winds north of the Equator; during the "winter" half-year the currents run generally westward under the influence of the north-east monsoon. For the rest of the year (April to October), "summer," under the influence of the south-western monsoon, the waters flow in the opposite direction.

South of the Equator the great Mozambique or Agulhas current, an immense volume of warm water, flows at first in a south-easterly direction till it rounds the southern coast of Africa, and then passes into the Atlantic, after clearing Cape Agulhas. This current, where it meets the south-easterly current, produces a considerable elevation of the surface temperature of the sea, and, like the Gulf Stream, in its neighbourhood violent storms and high seas are often experienced. (The early name of the Cape of Good Hope, given it by Diaz, was the "Cape of Storms," but this ill-omened appellation was changed by King Emanuel of Portugal to the happier name it bears at present.) Another cold current flowing *eastwards* passes south of Australia and thence into the South Pacific; a small part dividing from the main stream turns northwards towards the Equator, lowering the temperature of the west Australian coast regions.

Of polar currents the best known is the American Arctic current, whose course southwards from Baffin's Bay, following closely the outline of the American coast, influences the temperature of those regions as far as latitude 40°, and serves to accentuate the difference of climate between corresponding latitudes in Europe and North America, the former being warmed by the influence of the Gulf Stream, the latter cooled by this Arctic current. Behring's Strait "being too shallow to admit of mighty undercurrents or to permit the introduction from the polar basin" of much water, the Northern Pacific has no corresponding polar current. Similarly, there being no escape for the warm Pacific waters into the polar basin, they are turned "down through a sort of North

Sea along the western coast of the continent (of America) towards Mexico" (Maury). They appear as a cool current, and give freshness and strength to the "cooling sea-breeze of the Californian coast in summer time."

The polar currents of the Southern Hemisphere are of extensive influence, and form important features of the physiography of that part of the world. The Peruvian or Humboldt current has already been mentioned, but there is also a well-marked stream in the South Atlantic impinging on the south-western coast of Africa, and indeed it is sometimes stated that almost all the surface water between the Antarctic Circle and latitude 45° S. is drifting northwards and eastwards.

Thus by these currents, flowing in various directions, some carrying water hotter than the surrounding sea, others carrying cold water and sometimes icebergs, there is a constant circulation of the waters of the ocean. "Westerly currents generally flow round the earth on low latitudes, and counter-currents flow eastwards close to the Equator" (Scott).

Currents of hot water flow Polewards from the Equator, cold currents flow from the Poles towards low latitudes, and thus produce the compensation necessarily wanted to maintain the general level of the ocean surface, to prevent a permanent heaping up of the waters in one place, or a defect in another.

With regard to the *cause* of these currents, it is evident that differences of specific gravity are all-sufficient, but much speculation may be indulged in as to whether these differences arise more largely from differences of *temperature* or of *saltness*. The river waters running into the sea tend to diminish its saltness, whilst evaporation produces the reverse effect, the former lowering and the latter raising the *specific gravity*: an increase of temperature acts similarly to the first; a fall of temperature, by radiation or otherwise, increases the specific gravity. On the whole, notwithstanding these various actions, the mean specific gravity of the water of the sea undergoes no change, though in certain land-locked basins, such as the Baltic, there is to be found brackish rather than salt water.

Since the water in polar seas contains a slightly smaller proportion of saline matter, etc., than the average, owing to the melting of icebergs, whilst the greater evaporation at the Equator causes the proportion of salt to be larger, the influence of greater or less saltness tends in the contrary direction to that of temperature. The lower temperature of the polar waters increases their specific gravity, which the greater freshness would diminish, whilst the waters of the equatorial seas, rendered lighter by the influence of the sun's heat, are made denser by concentration of their salts owing to the rapid evaporation at the surface.

Thus by means of these warm and cold currents the ocean acts as a most important regulator and moderator of terrestrial climates. It carries a very large part (perhaps half) of the sun heat falling on the tropical zones to higher latitudes, there warming them, and conversely by means of the cold polar currents it serves to modify the otherwise excessive heat of many parts of the tropics. On account of the great specific heat of water, the latter is but slowly raised in temperature by a considerable accession of heat, and cools slowly on its withdrawal. "All the rivers run into the sea, yet the sea is not full," said the old Hebrew writer, and supplied the answer: "Unto the place whence the waters comes, thither do they return," evaporation making up for the addition. An enormous amount of heat, rendered latent in the process of evaporation and given out again in condensation, is conveyed from place to place, having been thus indirectly derived from the sea. The great evaporation of water in the Red Sea raises its density, and would lower the level of its surface by from 10 to 20 feet in a year were it not for a current of fresher water from the Indian Ocean pouring in through the Straits of Bab-el-Mandeb. Since there is no perceptible change in the density of the water, notwithstanding this excessive evaporation, it would seem that there must be a deep undercurrent of salter water back to the Indian Ocean, and an underflowing outward current in the Mediterranean, below an inflowing upper current through the Straits of Gibraltar (Mill).

CHAPTER XI

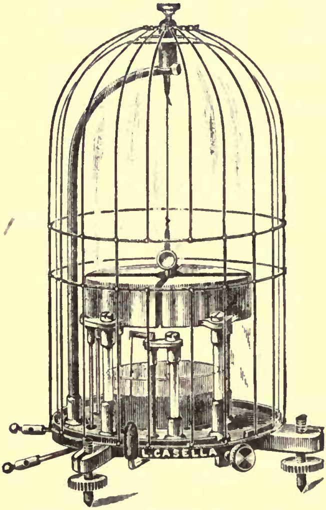
ATMOSPHERIC ELECTRICITY—INSTRUMENTS—QUADRANT ELECTROMETER—PORTABLE ELECTROMETER—THUNDERSTORMS—LIGHTNING CONDUCTORS—ST ELMO'S FIRE—ELECTRIC "HUM"—THE AURORA—MAGNETIC STORMS—MAGNETIC AND TRUE BEARING.

THE atmosphere is ordinarily found to be more or less in a condition of electrical instability; in fine weather usually positively charged to a greater or less degree, in broken weather it is often negatively charged. In addition to this we have the phenomena of thunderstorms, and the aurora, which, according to its appearance, is known as "Borealis" or "Australis" respectively, is seen in high northern and southern latitudes, but rarely near to the Equator. Our knowledge of the phenomena of atmospheric electricity has been much extended of late years by the work of Lord Kelvin, whose electrometer and water-dropping collector are most useful for their observation. Quetelet at Brussels and Everett in Canada have made observations with these instruments and obtained some interesting results. The former found that the daily indications during fine weather showed two *maxima* in summer, at 8 A.M. and 9 P.M.

respectively, and in winter at 10 A.M. and 6 P.M., the two *minima* being about 3 P.M. and midnight, the intensity of electrification being much greater in winter than in summer. At Kew the maxima and minima occur at somewhat different hours, whilst in Paris it is stated that M. Mascart finds only one *maximum* just before midnight. The electrification diminishes from sunrise till about 3 P.M., when it reaches a *minimum*, after which it rises to nightfall (Thompson). (Messrs Ebell and Kurz *at Munich* find two daily maxima and two minima for the summer, but only one for winter, for both positive and negative *ionisation*).

As a general rule, the air over the earth's surface is positively electrified with reference to the surface of the ground, the lower air is almost a non-conductor, whilst the upper regions, where the air is rarefied, conduct an electric charge somewhat in the manner of the rarefied gases within a Geissler tube, and are usually positively charged. Thus the lower air acts as the dielectric between the upper charge of positive electrification and the negative charge on the earth's surface. By measurement at different heights it has been found that the potential of the air gets higher as we ascend. Lord Kelvin found that the rise of potential was about 40 volts per foot (or 1·3 volts per centimetre) for Aberdeen (Thompson). Though, as we have said, the air is generally positively electrified in fine weather, during rain and broken weather the electrification is often negative, and undergoes rapid changes. A definite change in the electrical conditions usually accompanies a change of weather (Thompson).

The simplest instrument for detecting the presence of a charge, and its sign, whether positive or negative, is the electroscope, such as the Gold Leaf or Bohnenberger's, described in most books on electricity. As, however, indications are very feeble near the ground, the earlier observers affixed an insulated pointed rod to the top of the electroscope, or shot up into the air an arrow connected by a wire with the apparatus. Volta's method was either to use a slow-burning match attached to the top of a long metal rod, or else he employed a flame burning at a height. The particles discharged (and heated air driven off) from the flame thus serve to equalise its potential with that of the surrounding air; each particle as it leaves carries with it a small charge, + or – as the case may be, till the potentials of the rod and the air around are the same. The same thing is also effected by means of Lord Kelvin's "water dropping" collector. This is an insulated copper cistern, having a nozzle protruding into the air. This can being filled with water and the tap turned slightly on, so that a small stream of water pours gently out in drops, in a very short time its potential will be found to be the same as that of the air at the point of the nozzle. During frosty weather pieces of blotting-paper steeped in a solution of nitrate of lead, dried and rolled into matches, which when ignited smoulder slowly, are used instead. For examining and measuring the charge either Lord Kelvin's quadrant electrometer or his portable electrometer are the most convenient instruments. M. Quetelet's observations, already alluded to, were made with Peltier's electrometer. The Quadrant Electrometer designed by Lord Kelvin for the accurate measurement of small charges consists essentially of a needle made of a thin flat piece of aluminium, hung horizontally by a thin wire thread, or by two fine wire or silk threads, whose distance apart can be varied slightly. The needle carries at its top a small light mirror, whereby its movements can be accurately observed by watching the image of a scale reflected in it.



Quadrant Electrometer.

This needle swings inside a brass box, in which are four quadrant pieces, placed just below the needle without touching it or one another.

Opposite quadrants are joined by wires. Then if, say, quadrants 1 and 3 are slightly + as compared with 2 and 4, the needle will move from the former more nearly towards the latter, if positively charged, and the reverse way if negative, according to the usual law of electrification, positive charges being repelled by positive and attracted by negative—"like repels like, and unlike attracts unlike." When the differences of potential are small the deflexions, also small, will be very nearly proportional to these differences, and the instrument is sufficiently delicate to show a difference of potential between the quadrants of less than $\frac{1}{50}$th that of the Daniell's cell. A small charge must be imparted to the needle by means of an electrophorus or otherwise. One of the electrodes or wires, joining one pair of quadrants, is then joined or connected by a wire to the water-dropping collector, the other, joining the opposite pair, is connected with "earth" by means of a wire to a gas-pipe, or otherwise. Additional refinements, such as the use of two sets of quadrants instead of one, a "replenisher" to keep up the charge, and pumice soaked in sulphuric acid to absorb the moisture and keep the interior of the instrument dry, are often employed, but the needle and quadrants are the essential features.

The portable electrometer is a form of the "attracted disc" instrument, originally designed by the late Sir W. Snow Harris, but improved by Lord Kelvin. This consists of a small glass Leyden jar, having inside it an attracted disc and guard plate, which are placed in communication with a condenser to keep them at a known potential. The condenser is provided with a gauge, itself also an attracted disc, to indicate when it is charged to the right potential, and with a small influence machine to act as a replenisher and increase or decrease the charge if necessary. As with the quadrant electrometer pumice-stone soaked in sulphuric acid helps to keep the interior of the instrument dry, and thus prevent too rapid loss of charge.

In addition to the slight continuous indications of electrification already referred to, the phenomena of thunderstorms, and perhaps the more violent atmospheric disturbances accompanying "water-spouts" and hailstorms, come under the heading of atmospheric electricity. Benjamin Franklin, by sending up a kite with an iron point during the passage of a storm, found the wetted string to conduct electricity downwards, and was enabled to draw an abundance of sparks, which could be used to charge Leyden jars and produce all the electrical effects associated with the "static" electricity of the frictional machine, thus demonstrating the identity of the electricity of a thunder cloud with that obtained from the latter. In France Dalibard, at Marly, near Paris, erected an insulated iron rod, whence he drew sparks from the clouds during a storm, and Richmann, at St Petersburg, experimenting with a similar apparatus, was struck by a spark and killed on the spot.

There is still a good deal of uncertainty as to the cause of the excessive accumulation of charge shown in these vast developments of atmospheric electricity, and new "theories of thunderstorms" continue to make their appearance from time to time in the scientific and popular magazines, one of the most recent being outlined in *Nature* for 17th November 1910. This is due to Dr Simpson, of the Indian Meteorological Department. He supposes that upward currents of air prevent rain that would otherwise be deposited, from falling. The rain drops grow "through cycles of growth," then break up with separation of electricity, until their charge is so great as to produce a gradient of more than 30,000 volts per centimetre. Then the lightning flashes, and the accumulation is neutralised over a limited area; the process goes on again, another flash takes place, and so on, till equilibrium is finally attained and the storm ceases.

An outline theory of thunderstorms, favoured by Dr S. P. Thompson, may be here briefly sketched. The clouds are usually more or less charged with electricity, mainly derived from evaporation going on at the earth's surface. The minute particles of water vapour floating in the air become more highly charged. As they fall and coalesce[1] the strength of their charges increases; for eight small spherical drops equally charged will unite into another sphere of *twice* the radius ($2^3=8$), but having *eight times* the quantity of charge, and therefore the potential of the larger sphere will be $\frac{8}{2}=4$ times that of each original smaller one. Thus a mass of cloud consisting of such drops will rise in potential by their coalescence, the electrification at the lower surface becoming greater and greater, whilst the earth below becomes oppositely charged by influence; the layer of air between acting as the dielectric, the whole arrangement will become, as it were, a kind of condenser. After a time the difference of potential will be so great that the air between will give way, and a disruptive charge take place along the path of least resistance. Other discharges will also take place, since the first will only discharge the electricity at the surface of the cloud, and the other parts of the cloud will next react upon the discharged portion, so that a series of flashes will result. The discharge, known as the lightning flash, may be of one or other of three kinds:—(1) *forked or zigzag* lightning; (2) *sheet* lightning; (3) *ball* or *globular* lightning. Of these forms the most common is the first, the zigzag form, less evident

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[1] Lord Rayleigh, by experiments with electrified water jets, found that slightly charged drops have a tendency to coalesce (1879).

from photographs than it appears to the unaided eye, and is probably due to the presence of obstacles, solid particles or local electrification at various points, so that a crooked path, though longer than the direct one, is a line of least resistance. Sheet lightning, usually seen on the horizon at night time without thunder, is the reflection on the clouds of flashes from a distant storm. The third form, globular or "ball" lightning, is very rare, the appearance of incandescent "balls of fire" which move slowly along and then explode. It is probable that some of these recorded balls, if real, are not electrical phenomena, but meteoric masses from outer space rendered incandescent by passing through the atmosphere; but there seems no reason to doubt that this kind of discharge occasionally occurs, since similar phenomena have been accidentally produced in the discharge of electrical apparatus.

"Cavallo gives an account of a fireball slowly creeping up the brass wire of a large highly charged Leyden jar and then exploding as it descended, and Planté has observed similar but smaller globular discharges from his 'rheostatic machine' charged by powerful secondary batteries."—S. P. THOMPSON.

The sound, "thunder," heard directly after the lightning flash, though the common parlance "thunder and lightning" might seem to indicate the reverse, is due to the heating effect of the discharge. The spark heats the air in its path, and causes a sudden expansion (partial vacuum), followed by a rush of air from surrounding regions to fill up this partial vacuum. If the path be nearly straight and fairly short, one sharp loud clap is heard; but if the path be long and broken, there will follow a succession of sounds rattling after one another, whilst the echoes from the clouds will come rolling in afterwards. Owing to the fact that the speed of light is enormously great (186,000 miles per second in vacuo, and only slightly less in air), the flash is seen almost the instant that it is produced, but the speed of sound in air being only about 1,100 feet per second, or, roughly, 1 mile in five seconds, the reports from the clouds at different distances from the observer will be heard one after the other in order of their distance. By counting the interval of time between the flash and the sound of thunder, the observer may estimate his distance from the thunder-cloud (allowing 1 mile for every five seconds), and from the longer or shorter interval between flash and report he may ascertain whether the storm is receding from, or approaching towards, his station.

The physiological, though somewhat erratic, effects of lightning in causing death to man and other animals, destruction more or less complete to buildings, especially such as are lofty and unprotected, are largely described by Flammarion and other writers.

Just as we owe the discovery of the electrical nature of lightning to the genius of Benjamin Franklin, whom his own king and countrymen in later days ungratefully excluded as a traitor, though he was in reality a far greater benefactor to the human race than those who reviled him, so, too, to him is due the suggestion of lightning conductors. Knowing that "electricity" travels by preference along metal rods and other good conductors, he proposed to erect "upright rods of iron made sharp as a needle," and from the foot of those rods a wire down the outside of a building (church, house, etc.) to the ground, whereby "the electrical fire might be drawn silently out of a cloud before it came near enough to strike." On the principle that there is no free charge on the inside of a hollow conductor, the late Clerk Maxwell proposed to cover the outside of houses, etc., with a network of wires, thus shielding the interior from external storms.

A good deal of discussion has arisen of recent years as to the best *material* for lightning rods or conductors, and the controversy between Sir Oliver Lodge and Sir W. Preece of the Post Office on this point is well known. Sir Oliver Lodge, holding that the lightning flash is of an oscillatory nature, which indeed is now well known to be the case with the discharge of the

Leyden jar, shows that the best conducting substance (copper) is not necessarily the best material for a lightning rod, and that on the whole iron is to be preferred, though its electrical "conductivity" is less than that of copper for continuous current. It has also the advantage of being cheaper. Sir Oliver Lodge has shown that apparently similar lightning discharges may take place in at least two distinct ways, for one of which the ordinary form of lightning conductor, as usually set up, is of no service. To secure full protection under all conditions, it has been suggested to replace the single rod of Franklin by a network or skeleton of rods or wires enclosing the building it is desired to defend. All parts of this network should be in good metallic connection with metal work, pipes, etc.; metal inside and outside the building should be connected to it, and it should be in good connection with the earth at as many points as possible. To secure that the earth connection is good, the *earth plates* should be at such a depth as to be in contact with water or moist earth all the year round (Stewart).

"Modern views of electricity," as well as the singular behaviour of lightning in sometimes persistently avoiding "good" conductors and travelling where least expected, have shown that the whole matter is not so simple as the "practical man" has been hitherto inclined to suppose.

"Currents" do not flow *through* conductors, and the lightning flash, with its surgings and "splashes," often seems to avoid good conductors, and choose out apparently worse and more erratic paths. A hollow core of metal seems as good as a solid rod, and the phenomena of "self-induction" render iron, though a less good conductor than copper, a better guide for the "electric fire of Nature."

Hail, "frozen rain," is frequently thought to be in some way caused by electrical action, though doubt has been thrown upon this connection. Certain it is that hail most commonly falls during thunderstorms, whether in summer or in winter. It has been supposed that raindrops are carried upwards into the higher regions of the air, where they become solidified at the low temperature there prevailing, and fall again, sometimes rising once more. These alternate meltings and freezings taking place, the hailstones sometimes increase to a great size, sometimes over one foot in circumference. Much damage is done by hailstones in tropical countries, and sometimes also in parts of Europe, as is also related in chap. ix.

During a thunderstorm the appearance of the sky is usually very characteristic, the expression "thunder-cloud" being well known. The heavy, cumulus clouds, with admixture of cirro-stratus above and "cloud curtain of loose texture below," sometimes produce intense darkness. The cirro-stratus clouds, when coming in front, may sometimes be 10 to 50 miles in advance of the storm. After this come the "thunder-heads" of cumulus clouds, and under this the "rain curtain," with a "squall cloud" below (Archibald). When the "squall cloud" arrives, the wind changes in direction, the air becomes cooler, and the barometer rises slightly. Then the rain or hail begins to fall, the lightning flashes, and the thunder rolls, until the centre of the storm passes. In general, thunderstorms are associated with great differences of temperature in adjacent air masses, and two classes of storms are usually defined:—(1) heat thunderstorms, and (2) cyclonic thunderstorms. The former are chiefly confined to tropical regions, and to the summer time in more temperate climates; the latter may occur also in winter, are characteristic of our own Atlantic coasts, and are so named from their connection with cyclonic disturbances. They are not so dependent on sun heat as the other kind, frequently take place at night, and come along accompanied by gales of wind. Though not so violent as the heat thunderstorms, they are perhaps more dangerous, since the clouds being at a lower level, the lightning discharges more frequently strike the ground.

One theory as to their occurrence is that they are due to the ascent of warm moist air by convection. In "summer storms" the cloud is isolated and continuous, often from 1,000 feet upwards to the cirrus level of 30,000 feet. It spreads out in a sheet in all directions, so that a thunderstorm cloud of this kind often presents the appearance known by the name of "anvil shape" (Archibald). The cyclonic thunderstorms are supposed to be due to the cooling of the upper air producing similar effects to the heating of the warmer air, in disturbing electrical equilibrium.

There is both an annual and a diurnal periodicity in the frequence of thunderstorms. More storms occur in summer than in winter, and the "summer storms" are most frequent in the early afternoon, when the temperature is at its highest for the day. The winter storms of the "cyclonic type," on the other hand, though less frequent than the "heat" thunderstorms, occur at all hours, frequently during the night; they are more frequent on the Atlantic seaboard (western coasts) than on the other, because owing to the proximity of the sea, great contrasts of temperature at different heights in the atmosphere less frequently arise. Nevertheless, that storms are associated with sudden changes of temperature is evident from the fact that hail so often falls during their occurrence, and that the thunder-clouds are mainly of the cumulus type, whose presence indicates the existence of a colder and drier layer of air immediately above that in which the clouds form; and thirdly, changes of wind occur during their continuance, occasioning a rapid fall of the thermometer.

"The way in which changes of temperature tend to produce electrical disturbances is not as yet explained, but it is undeniable that they form an essential condition for the generation of a thunderstorm."—SCOTT.

The thunderstorms in Iceland all occur in winter, yet it was at one time supposed that they were quite unknown in Arctic regions. On the other hand, they are of daily occurrence, and often of terrific grandeur, in the tropics, such as we in more temperate zones can form no idea of. Even in South Africa fearful storms are of frequent occurrence. In Abyssinia the number of four hundred and ten thunderstorms was given as the average annual quantity from four years' observations by D'Abbadie; nearly all of these happened in the afternoon hours. Out of one thousand nine hundred and nine storms recorded in six years, only twenty-two occurred between midnight and 11 A.M. (Scott).

Of a somewhat different character from ordinary lightning is the luminous appearance known usually as "St Elmo's fire," a phenomenon sometimes observed during thundery weather. Brushes of pale bluish light are seen playing at the tops of the masts of ships, tree tops, and other pointed objects, and the whole phenomenon seems of the same nature as the "glow" or "brush" discharge of a frictional electrical machine, as indeed was noticed by Franklin, who, as already stated, first drew attention to the similarity of the phenomena of lightning and "frictional electricity." In ancient times this appearance seems to have been considered an omen of good fortune for those by whom it was seen, and, unlike lightning, no damage follows from its manifestation. In more modern times we find the son of Columbus saying that the sailors heralded the appearance of "St Elmo" as a sign that the fury of the storm was over. It is sometimes accompanied by a hissing noise like that made by damp powder when ignited. It is stated that a similar appearance has been seen at the end of weapons. The soldiers of Cæsar's fifth legion were once alarmed by noticing that the ends of their lances seemed to be on fire, and a similar phenomenon happened during the campaign of Belisarius against the Vandals (Flammarion).

A rarer phenomenon accompanying the discharge is a kind of electric "hum" or buzz, sometimes heard on mountain tops, vouched for by M. de Saussure. He, with several friends, ascended the summit of Sarley in the Grisons on the 22nd of June 1867. After a shower of sleet the members of the party had laid by their alpenstocks and were resting to take a meal, when M. de Saussure felt a pain in his back, like that which would be produced by driving a pin slowly into his flesh! Thinking that his overcoat had pins in it he took it off, but the painful feeling increased. On examining his underclothing, he found nothing to cause this sensation. Meanwhile, he noticed a sound which reminded him of the humming of bees, and at the same time he noticed that the sticks of himself and companions, which were resting on the rocks, gave forth a loud singing noise like that of a kettle when the water is on the point of boiling. He then understood that the painful feeling in his back proceeded from an electric flow which was going on from the summit of the mountain. Experiments with the sticks did not cause the latter to emit any light or luminous appearance that could be detected. After a short time "they all felt strong currents escaping from their clothes, ears, hair, and all the prominent parts of their bodies, as well as from the sticks, and hastily left the summit of the mountain" (Flammarion).

The Aurora (Borealis or Australis, according as it is seen in the Northern or Southern Hemispheres respectively) is also a phenomenon evidently of an electrical character, and so comes properly under the subjects treated of in this chapter.

It is an occasional phenomenon in this country, the "Northern Lights" in popular parlance, but within the Arctic Circle it is of almost nightly occurrence; according to Nordenskiold the terrestrial globe is perpetually surrounded at the Poles with a ring of light, to which he gives the name of the "aurora glory." As seen from Europe, it usually appears in the form of a number of streaks or streamers of a reddish tinge (occasionally mingled with other colours), which either radiate in a fan-shape form from the horizon nearly in the direction of the magnetic north, or else they form a kind of arch in the sky whose head is northwards. The whole generally has a characteristic, unsteady, and vibrating appearance, the streamers flickering and varying both in colour and brightness, being usually very faint, but occasionally of considerable brilliancy. The appearance of a brilliant aurora is usually accompanied by irregular disturbances of the magnetic compass needle all over the world; in other words, what is called a "magnetic storm." The needle, apart from its general north and south direction, and the slow daily oscillation backwards and forwards from a mean position, at times moves in a much more irregular manner.

These movements, though very small in amount, are known by the name of "magnetic storms," and are often sufficient to interfere with the regularity of telegraphic signalling. They have some as yet unknown connection with outbursts on the sun, the appearance of large sunspots and unusually bright prominences occurring simultaneously with auroras and magnetic storms on the earth. This has been strikingly shown on various occasions. On the afternoon of 1st September 1859, Messrs Carrington and Hodgson, observing the sun simultaneously, saw two luminous objects make their appearance on the disc at the edge of a great sun-spot, of a brightness, at least, five or six times that of the neighbouring regions of the solar surface "photosphere." These objects moved over about 36,000 miles in five minutes, and then disappeared. A great magnetic storm and brilliant aurora followed on the same night. On 3rd August 1872 the late Dr Young observed that the chromosphere[1] in the neighbourhood of a sun-spot was greatly disturbed, and jets of luminous matter of intense brilliance were projected upwards.

Magnetic storms were recorded at Greenwich and Stonyhurst, as nearly as possible at the same moment that these disturbances were seen in America. In September 1909 a very large composite sun-spot, which underwent frequent and striking series of changes, crossed the central meridian of the sun's disc on the 23rd, directly after which "there broke out the most intense magnetic storm experienced for more than a third of a century." At night, auroras of great brilliance were seen, both in Europe and in the Southern Hemisphere.

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[1] The chromosphere is a layer surrounding the sun's disc, visible only by the help of the spectroscope, in which "prominences" appear from time to time. It is so named from its usually coloured (red, etc.) appearance.

It is thus fairly evident that there is some intimate connection between solar outbursts, magnetic storms, and terrestrial auroras, though it does not follow that the former in any sense "cause" the latter.

It may perhaps be as well to state that neither a magnetic storm nor an aurora is accompanied by any simultaneous development of atmospheric electricity or thunderstorm, properly so called. The term "magnetic storm" may perhaps appear somewhat of a misnomer, for the most violent movements of the needle are, after all, only very minute, never exceeding a few minutes of arc to the right or left of its mean (undisturbed) position. The *ordinary* movement of the compass needle in this country exhibits a *daily* and annual *variation* somewhat as follows:—

About 7 A.M. the needle moves towards the west till about 1 P.M., and attains a "westerly declination" of about 8′ to 10′ from its mean position, then it slowly travels back eastwards till about 10 P.M.; it then usually remains quiet, or nearly quiet, till the following morning, but in summer time it sometimes moves again slightly westwards and back again during the early morning. These changes appear to be in some way connected with the sun's position, and perhaps the moon, too, may also be concerned in these movements, which are smaller in winter than in summer. There is also an annual variation both in declination and intensity, the "total force" being greatest in summer and least in winter, whilst the angle of dip, or the angle which a freely suspended magnetised needle makes with the horizon, is subject to small seasonable changes, apart from the *progressive* changes in these elements.

Though perhaps somewhat outside our subject, we may just mention these latter phenomena. The magnetic needle, though pointing very nearly north and south, does not exactly do so, but at present its *mean position* makes an angle of about 15° (in London, 1910) with the true geographical meridian (north and south line), which deviation is called the *magnetic declination.* This declination is not the same everywhere, or for all time, but varies both in time and place. It is greater for places to the westward of England and Ireland than it is for London and the eastern counties, and the difference in angle is about 6° for the limits of the British islands. One end of the needle points (roughly) northwards, the other end southwards; these are called the "north-seeking" and "south-seeking" poles respectively. In London, at present, the north-seeking end makes an angle of about 15° to the *westward* with the true meridian; in Galway this angle is about 20° W. This deviation of the magnetic meridian from the true north and south was known to the Chinese in very early times, for their authors mention magnetic carriages showing "direction towards the south"; but the discovery, so far as Europeans are concerned, is often attributed to Columbus, who found that in sailing across the Atlantic he came to a region where the needle pointed *due* north and south. The line passing through places where there is no declination is called the "agonic line."

In addition to this variation from place to place we find that *at the same place* the declination undergoes a *progressive* change, as apart from the small temporary diurnal and annual changes and those associated with so-called magnetic storms. When first noticed, about 1580, the north-seeking end of the compass needle pointed about 11° to the *east* of true north (at London). During the seventeenth century this easterly declination decreased till, in 1657, the declination was zero, and London was then on an "agonic line." After this, the progressive movement continuing in the same direction, the north-seeking end now pointed (and points) *westward* of the true meridian, increasing from 0° (in 1657) to a maximum of 24° 27′ in 1816, after which it has slowly diminished at the rate of about 7′ per annum. It has been estimated that it will again point truly north and south in about sixty-five years time, having made a complete cycle in about three hundred and twenty years (Thompson). Throughout the world the declination is changing in a similar manner, though the cause is as yet quite unknown. The angle of *dip* or deviation from the vertical, shown by a freely suspended magnetised needle, also undergoes variation both from time to time and at different places. One end usually dips downwards, the other upwards, though this is scarcely noticeable in the ordinary form of the horizontally suspended compass needle. In our latitudes the north-seeking end dips *downwards*, and the angle of dip is now slightly under 67° (London in 1910).[1] In 1576 the inclination was about 71° 50′ (Thompson); this increased to 74° 42′ in 1720, and then diminished again to its present value, and is still diminishing. At the north magnetic pole (near Boothia Felix, latitude 70° N.) the north-seeking end of the needle points straight downwards, and the dip is consequently 90°; at the magnetic equator the needle is horizontal and the dip zero. Lines joining places where the dip is the same are called *isoclinic* lines, roughly corresponding to the lines of latitude on a geographical map, whilst the isogonic lines still more roughly correspond to meridians of *longitude*. The "aclinic" line (line of no dip) may be called the magnetic equator, whilst the points where the north- or south-seeking ends respectively dip vertically downwards

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[1] The mean declination at Greenwich for 1909 is given as 15° 47′ W. Mean dip, 66° 53′ 57″. "Astronomer Royal's Report to Board of Visitors, 18th June 1910."

(angle of dip 90° N. or 90° S.) may be (and are) called the magnetic poles. The third element (after declination and inclination), magnetic intensity or intensity of the force, whatever it may be, that causes the needle to set itself as it does, is also subject to variations, corresponding with those of the two other elements, both in its amount from time to time and in different places, but need not be further dwelt upon here.

One caution may perhaps not be out of place in connection with meteorological observations in reference to observations of wind direction, the position of weather vanes, etc. Many persons take their directions from a compass, in ignorance of the fact of magnetic declination we have just mentioned, the deviation between *true* and magnetic north and south. In London and eastern England this difference amounts to about 15°, and is yearly diminishing, but in Ireland it may amount to over 20° (or nearly two points of the compass), and it was greater in this country also during the last century.

Thus a vane set up by the help of a compass, no allowance being made for this variation or declination, will have its north point really turned towards N.N.W., its east point will really be 15° to 20° to the north, and so on. The compass card being divided into thirty-two points, and there being 360° in the complete circumference, one point will be $\frac{360}{32} = 11\frac{1}{4}^\circ$ and two points $22\frac{1}{2}^\circ$, between which values the declination will lie for these islands, this being, as already stated, least for eastern England and greatest for western Ireland, increasing in a roughly westerly direction, the *isogonic lines* running N.N.E. and S.S.W. An error of two points may thus arise in giving records of wind direction, quite apart from any errors arising from the sluggish movements of weather vanes.

[*Note on the Aurora.*—Examined by the help of the spectroscope, the light of the aurora is shown to be due to gaseous matter, but all the lines of the bright line spectrum are not yet identified, one or two being not yet recognised as due to any known substance, though similar in character to those given by the electric discharge in highly rarefied air. This was indeed the explanation of it given by Franklin long before the days of spectrum analysis, and still seems the most generally accepted theory. The cold air near the Poles and currents of warmer air and vapour coming from equatorial regions certainly must differ in electric potential, and discharges will take place between them. Another theory supposes the aurora to be due to differences of potential set up in the upper regions of the air by the inductive action of the earth rotating within a less rapidly rotating shell of outer atmosphere! The height of the auroral display above the earth is found by Dr Paulsen to range between 61 and 67 kilometres (about 40 miles), though apparently the fiery trains never seem to reach the surface of the earth, and they have been observed lower in elevation the further north they have been met with (Inwards).

An artificial aurora was produced by Professor Lemström, of Helsingfors. He erected on a mountain in Lapland a network of wires and rods which presented many points to the sky. He was thus able to send beams of electricity into the air, and observed columns of light ascending from his apparatus more than 100 yards into the air. By insulating his apparatus and connecting it by a wire with a galvanometer at the bottom of the mountain, he was able to observe actual currents of "electricity" when the "auroral beam" rose above the mountain.]

CHAPTER XII

SEASONAL VARIATIONS OF WEATHER—RECURRENT TYPES—BUCHAN'S HOT AND COLD PERIODS—INDIAN SUMMER—ST LUKE'S SUMMER—ST MARTIN'S SUMMER—MAY AND NOVEMBER COLD SPELLS, ETC.—SOUTHERLY, NORTHERLY, WESTERLY, AND EASTERLY TYPES (ABERCROMBY)—SOUTHERLY TYPE—WEATHER CONDITIONS—WESTERLY TYPE—NORTHERLY TYPE—EASTERLY TYPE—DISTRIBUTION OF PRESSURE OVER THE GLOBE—POLAR CYCLONES—THE DOLDRUMS.

THE heat of summer and the cold of winter, accompanied by a greater amount of fine weather in the former, and more rain and unsettled conditions during the latter period, constitute what we may call the normal or expected condition of affairs, though in our own country local and temporary irregularities draw so much attention to themselves that many persons will be inclined to think that the exceptions are more frequent than the rule. Over the whole earth, however, we may distinguish three characteristic regions:—(1) the equatorial belt of calms, the "doldrums" region; (2) the tropical belt, "region of trade winds"; (3) the "Temperate and Arctic Zones." The equatorial belt forms a kind of hollow between the two trade wind regions on either side of it. North and south of this on either side we have the trade wind areas, where for months at a time the same wind blows continuously. In the Northern Hemisphere we have the north-east trade wind, caused by air blowing from the Poles towards the Equator and deflected by the effect of the earth's rotation towards the right, and a south-western "anti-trade" wind coming from the Equator towards the Poles. These winds are less marked over the continents than over the ocean, owing to the influence of the former in modifying their direction and disturbing their regularity; but in the Southern Hemisphere such winds are so well marked and strong that the zone of latitude in which they are principally felt is known as "the roaring forties" (40° S.). The influence of the ocean in modifying climates, by means of the currents of warm and of cold water it conveys from place to place, by the latent heat of evaporation and condensation of its water, raised into the air in enormous quantity through the action of the sun's heat, is perhaps the most important of any agency in altering what one might perhaps call the astronomical or latitudinal conditions, *i.e.*, such as might be supposed to exist with no ocean or atmospheric circulation.

In our own country, and throughout North-Western Europe, in addition to the general course of the seasons, from the heat of summer to the cold of winter, we have more or less recurrent periods of from three days to one week in length, during which periods year after year we have similar weather. A number of these periods have been discovered by meteorologists, and six cold and three hot periods are known by the name of Buchan's hot or cold spells respectively.

The "cold days" of May, the Lammas flood period, St Luke's and St Martin's summers respectively, are well known. The following short account of the chief of these periods, whose regular return seems well established, is chiefly given on the authority of Mr Abercromby ("Weather").

From 7th to 10th February is a spell of cold weather — Buchan's first period. The weather of this period is associated with what is called the "northerly type," or pressure high over Greenland and the Arctic portion of the Atlantic Ocean, and low over most of Europe.

The proverbial east winds of March, when they occur, are also usually due to the northerly type of weather, but there is little or no evidence for the supposed prevalence of equinoctial gales about the 21st. Indeed, neither at the spring nor the autumn equinox are the winds in this country, as a rule, of any exceptional violence, so that it seems somewhat extraordinary how so widespread an idea can have arisen.

11*th to* 14*th April.* — Buchan's second cold spell, the "borrowing days," supposed borrowed by March from April:—

> "March borrows of April,
> Three days and they are ill."

The difference of dates between the "old" and "new" style (Julian and Gregorian calendars) made 11th April on the latter follow 31st March on the former.

9th to 14th May.—Buchan's third cold period, the famous "three" (or six) cold days of May. All over Europe this periodical diminution of temperature occurs, due to the setting in of a spell of the easterly or northerly type. Fanciful theories as to the impact of a stream of meteors with the earth which cut off some of the sun's light and heat, and ideas as to the periodic passage of our planet through an extra cold region of space, have been promulgated, but such an occurrence would lower the temperature not only over Europe, but over the rest of the world also, which does not appear to be the case.

June.—A cold spell in the second or third week, accompanied by weather of the northern type. Eredia, in a recent paper to the Accademia Lincei, has clearly established the existence of this period of low temperature during the second decade of June throughout Italy, more pronounced in Lombardy and Venetia and the interior of Central Italy than in the coast regions. During this period there is usually a region of low pressure in Russia, and one of high pressure over Spain, so that the weather is of the "northerly" type.

29*th June to* 4*th July.*—Buchan's fourth cold period.

12*th to* 15*th July.*—Buchan's first warm period. July 15th is "St Swithin's Day," the popular legend as to the wetness or otherwise, "St Swithin is christening the apples," is well known, though resting on a very slender foundation. The occasional persistence of the weather current during this time for a fortnight or so, whether wet or fine, is an undoubted fact, but it nevertheless sometimes happens that a dry St Swithin's Day is followed by a good many wet ones, and *vice versâ.* What may have happened once is no promise that such a thing will occur again.

2*nd to* 8*th August.*—A wet period, the "Lammas floods" of Scotland (Lammas Day, 1st August).

6*th to* 11*th August.*—Buchan's fifth cold period.

12*th to* 15*th August.*—Buchan's second hot period.

24*th August* (St Bartholomew's Day).—"If it rains this day it will rain the forty days after." Thus St Bartholomew is a rival to St Swithin!

September.—Towards the end of the month, the "Indian summer" of North America is experienced; a fine period, lasting for three or four days.

18*th October* (St Luke's day).—A fine, quiet period about this time is consequently known as St Luke's summer.

6th to 12th November.—Buchan's sixth cold period, associated with weather of the northerly type.

11th November (St Martin's Day).—A fine, warm period of a few days about this time is known as "St Martin's little summer," both in this country and in more southern latitudes. "Expect St Martin's summer" (Shakespeare, *Henry VI.*, pt. 1, act 1, sc. 2).

3rd to 9th December.—Buchan's third warm period.

The general explanation of the recurrence of these cold and warm periods is to be found in the tendency to the recurrence of certain types of pressure distribution at or about the dates given above. Weather of the northerly or easterly type gives rise to the cold "spells"; weather of the southerly type in winter is attended by a warm period. Of the foregoing periods the cold spells of May and November are very regular in their recurrence from year to year, though not always exactly in the same weeks of the months; more often than otherwise "the cold period comes in the third week of each month" (Chambers). It is a popular superstition that a late Easter is accompanied by severe weather in this country, but we need hardly say that though instances of cold Easters are common enough, the evidence of statistics lends no countenance to this idea. Three warm periods during the autumn, the first about the end of September, the second about 18th October, and the third early in November, as already mentioned, are known popularly by the name of "summers"—Indian summer, St Luke's summer, and St Martin's summer respectively—and fanciful theories as to their cause and recurrence have been propounded, some attributing their warmth to the latent heat liberated during the condensation of vapour, or the freezing of water to form ice, etc.

Four principal types of weather, corresponding to four forms of pressure distribution, have been recognised by Mr Abercromby as occurring in these islands and throughout Western Europe generally, to which he has given the convenient names, from the prevailing wind in each, of southerly, northerly, westerly, and easterly respectively. In the first or southerly type the Atlantic anticyclone, so prevalent a feature of the Central Atlantic, whose range south and west is fairly constant, but which varies considerably in its northern limits, lies to the east or south-east of the British Isles, whilst to the north of it is a region of low pressure, in which cyclones are continually generated and come in, encountering a region of higher pressure over the continent, and either die out or pass towards the north-east. At times the low-pressure area, ordinarily over the North Atlantic, spreads into these islands and displaces the high-pressure region eastwards; during this state of affairs we have fine weather and little wind, with a low barometer. This type of weather is often prevalent during mild winters.

The broad sequence of weather conditions during the prevalence of this type is, roughly, as follows:—The barometer falls, the temperature rises, there is a gloomy sky, and drizzling rain sets in. The wind, usually southerly or south-westerly, backs slightly and increases in force. After a time the barometer ceases to fall and begins to rise again, the wind gradually falls, temperature decreases, and the sky becomes clearer. On the following day a similar sequence occurs, and this alternation sometimes lasts for days or even weeks at a time. Whenever a persistent spell of this type is seen to have set in, the work of the forecaster is fairly easy, for he has only to recur to his experience of former similar spells. The cyclones coming in from the Atlantic do not pass over, so that our country will only be under the influence of their fronts. Increases of intensity, rising in force to a gale or storm, may be expected from time to time, but the general character of the weather and direction of the wind remain without much change, till this type merges insensibly into the western on one side, or rather more abruptly into the eastern on the other side.

The *westerly* type of weather is characterised by the development of small cyclones on the north side of the great Atlantic anticyclone. These move quickly eastwards, and often die out after they have become detached from the latter. They vary greatly in intensity, and at times, when their centres cross these islands, destructive storms, especially occurring in spring and autumn, are experienced in their passage. Most commonly, however, their paths are further to the north, and the wind merely backs a little first from the south-west, veering towards the west afterwards, and is of moderate intensity, accompanied by some rain. Sometimes when the Atlantic anticyclone extends to the southern part of our islands, the north of Europe is covered by small cyclones, no rain is developed, but only cloud, with fine dry weather. This type is very common, perhaps the most frequent of all in our latitudes.

The general character of the temperature is about the average for the season, but in winter the influence of the wind prevents much frost, whilst in summer the temperature may be below the average if much cloud is present.

The *northerly* type is characterised by the presence of a large anticyclone over Greenland and the extreme North Atlantic. The latter sometimes unites with *the* Atlantic anticyclone so often referred to, or is only separated from it by a col. To the east of this, lying over the greater part of Northern Europe and Russia, there is a large area of low pressure, whence issue cyclones and secondaries. This type is exactly the converse of the southerly, the latter type presenting cyclone fronts and southerly winds to Europe, the former northerly winds and rear portions of cyclones. During the prevalence of this northerly type the sequence of weather is, roughly, as follows:—The barometer falls, the wind changes towards north-east with cloudy sky, then some rain falls, with increase of temperature. After a while the sky clears up, the wind backing through north towards north-west, the barometer rises, and the temperature falls. The sky throughout has a characteristic "hard" appearance, the general temperature will be below the average for the season, and the air will be in general dry from the prevalence of northerly winds.

The fourth type is that known as the *easterly* one. Here there is a fairly persistent anti-cyclone over Scandinavia, whilst the Atlantic anticyclone does not extend so far north as usual, but there is a col formed between the two which, crossing Europe, profoundly affects the course of the weather changes. Then the cyclones coming from the Atlantic either pass through this col in a south-easterly direction, or else they are arrested and remain over Western France and the Bay of Biscay. Occasionally cyclones forming on the southern edge of the

Scandinavian anticyclone have their centres over Southern Europe, and move *westward*, contrary to the almost general rule for cyclone motion. Thus, while for cyclones formed in the three previous types of pressure distribution the movement is always easterly, for the easterly type we may sometimes get westerly progression. During the persistence of this type the general character of the biting east wind is characteristic and well known. The temperature is generally low, the wind always from some point of east, occasionally veering towards south-east, or backing towards the north-east. In our islands this type of weather sometimes persists for two or three weeks consecutively, and gives rise to destructive storms. It is stated that nearly one half of the wrecks on the British coast are due to gales of this class (Abercromby).

These four types of pressure distribution describe most of the weather successions in Western Europe, including our own islands, and by reference to them considerable simplification of the "ceaseless and complicated changes" is introduced, though of course the simplicity of conditions prevailing in more tropical regions is still far off. The recurrence of certain kinds of weather at about the same time each year is to be referred to this tendency of types to repeat at definite times, whilst the changes of type are often fairly regular in character. Thus the southerly type may change gradually into either the westerly or the easterly, but not in any case into the northerly, the westerly type may become southerly or northerly, but not jump into easterly, each type changing only into its next neighbour on either side, never into its opposite (as east into west, north into south); for whilst a slight shift of pressure may modify one type into the next, a change to the opposite type would involve a total rearrangement of pressure over the whole Northern Hemisphere (Abercromby).

The most general description of the distribution of pressure throughout the globe is to roughly divide this into three zones:—(1) There is an equatorial zone of low pressure; (2) a tropical belt of high pressure; (3) a temperate and arctic zone of generally low pressure over which occasionally areas of high pressure appear for a considerable time. On the theory of Ferrel, the general circulation of the air may be considered as consisting of two huge cyclones, one round each pole, in which the air rotates in the same direction as that of the earth itself. On the equatorial side of each of these there is a belt in which the air rotates in the contrary direction. (These are the "trade-wind" belts.) Between these the air is heaped up into two regions of higher pressure, whose highest mean values occur at about latitudes 35° N. and 30° S. respectively. The equatorial belt lies over the Sahara in the old continent, and the

Amazon valley in the new; over the Atlantic Ocean the region is well known to sailors as the "doldrums," and much dreaded by them in the old sailing-ship days, for their ships lay often for weeks on the water without motion.

> "Day after day, day after day,
> We stuck, nor breath nor motion,
> As idle as a painted ship
> Upon a painted ocean."
> —COLERIDGE, *Ancient Mariner.*

These are regions of "unbearable calm broken occasionally by violent squalls, torrential rain, and fearful lightning and thunder."

The tropical belt, north of this "doldrum" region, comprises a region of high pressure; developing into great anticyclones, whose length usually lies east and west. Though most of these are formed in different regions from time to time, one is very constantly found over the Central Atlantic, and from its important bearing on the weather of Europe and the United States it is, as mentioned, called *the* Atlantic anticyclone. The north-easterly and easterly winds on the southern side of this anticyclone are known as the "trade winds." Few cyclones are formed to the south of this Atlantic anticyclone, but its north side is the origin of the cyclone storms, which, moving towards the east, give a prevailing character to European weather. On the south-east side a few cyclones occasionally form, which either work round slowly to the south-west, or else go eastwards over the Straits of Gibraltar.

The temperate and arctic zone extends from the tropical belt to the Pole. This, though in its general character as mentioned above, a region of low pressure, is continually varying in this respect, and large persistent areas of high pressure appear. Thus changeable weather with variable winds characterise this region (which includes our own islands).

GREENWICH OBSERVATORY (METEOROLOGICAL SECTION).

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CHAPTER XIII

OBSERVATORIES—FIRST ORDER, SECOND ORDER, AND THIRD ORDER STATIONS—GREENWICH OBSERVATORY—SELF-RECORDING INSTRUMENTS—KEW OBSERVATORY—SECOND ORDER STATIONS—THEIR WORK—BI-DAILY OBSERVATIONS—INSTRUMENTS—OBSERVATIONS—MORNING SERIES—EVENING SERIES—FORECASTS OF WEATHER—STORM WARNINGS—LIST OF DISTRICTS—DAILY AND WEEKLY WEATHER REPORTS—NOTE ON METRIC AND "ENGLISH" MEASURES—TEMPLE OF THE WINDS, ATHENS.

THROUGHOUT our islands, in addition to the larger institutions under Government auspices, such as the Greenwich and Kew Observatories in the neighbourhood of London, or the observatories such as those at Oxford (Radcliffe), Stonyhurst, Cambridge, Durham, etc., supported and maintained by the universities or other educational authorities, there are a number of other smaller meteorological stations, where regular observations of the barometer, thermometer, etc., are made daily; also, in most of these, records of rainfall, the amount of sunshine and general atmospheric conditions are observed. These are almost entirely supported by private enterprise, and much useful work is done, the results of which are sent in weekly and monthly reports to the Meteorological Office and other central authorities. Some of the larger of these institutions send also daily telegraphic messages, warning of coming storms, etc. Three classes of observing stations are semi-officially recognised.

A station of the *first order* is one in which meteorological observations are made by means of hourly readings, or the use of self-recording instruments (barometers, thermometers, rain-gauges, sunshine-recorders, anemometers, etc.).

A station of the *second order* is one where complete and regular observations of the air-pressure, force of wind, temperature of air and ground, moisture, cloud, rain, sunshine, etc., are made, usually *twice daily*.

A station of the *third order* is one where only some of these elements are observed. At some places there is only a rain-gauge installed, more than three thousand of such stations sending records of rainfall (measured daily at 9 A.M.), to Dr Mill, at Camden Square, London, head of the British Rainfall Organisation, under whose auspices a yearly volume, "British Rainfall," is published, giving the results of these (mainly volunteer) observations.

The earliest systematic meteorological observations were necessarily first made at astronomical observatories. All astronomical observations being made through the medium of the atmosphere, and the conditions of visibility, refraction, etc., depending so closely upon the temperature, pressure, and humidity of the latter, the necessity for accurate observation of these elements led to the regular reading of the barometer and thermometers by astronomers. At the Observatory at Paris, and the Royal Observatory, Greenwich, regular meteorological observations have been made almost from the foundation of these institutions; rainfall and temperature records at Paris extend over two hundred years. At Greenwich, founded almost simultaneously with the sister Observatory of Paris, the records are almost equally complete. Standard barometers, thermometers sunk at different depths in the earth (usually four, at depths of 24, 12, 6, and 3 feet respectively), are all regularly read at least once daily.

Stevenson and Glaisher screens containing wet and dry bulb thermometers, maximum and minimum self-registering instruments, are placed in the grounds, the newest addition being "the magnetic pavilion" enclosure. The Astronomer Royal's report for 1910 (the last prepared by Sir W. Christie) states that "registration of atmospheric pressure, temperature of the air and of evaporation, pressure and velocity of the wind, rainfall, sunshine, and atmospheric electricity, has been continuously maintained. Cloud observations, in connection with the international balloon ascents, have been made with a Fineman nephoscope." In a shed is placed the apparatus for photographic registration of the dry and wet bulb thermometers. The indications of these instruments are recorded by means of the following arrangement.

A sheet of sensitised paper is rolled round an upright drum, which is moved slowly round by clockwork, whilst a beam of light passing to a greater or less degree through the thermometer tubes, according to the height of the mercury column, after falling upon the paper, produces two traces upon the latter, each trace being bounded on one side by a wavy line, and thus automatically and continuously records the variations in temperature of the two instruments. The standard barometer is read directly at frequent intervals, and a continuous record of the variations of pressure is obtained by photography, in a similar manner to that in which the variations of temperature are recorded; light falling upon sensitised paper, being stopped to a greater or less degree, according as the height of the mercury column varies from time to time. A sunshine recorder, of the Campbell Stokes pattern, is placed on the top of the magnetic building, and records of sunshine have been obtained in this way since 1876. Various rain gauges, at different heights above the level of the ground, and self-recording rain gauges, are also in regular use. The self-recording rain gauge makes its record in the following manner. The rain falls into a vessel which is suspended by spiral springs. This vessel falls as it becomes

KEW OBSERVATORY (NATIONAL PHYSICAL LABORATORY).
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heavier, with more or less rapidity, according to the rate of rainfall. By means of a cord passing from the vessel, over a pulley to a pencil, the rate of fall is registered on a sheet of paper which is moved by a clockwork mechanism. When 0·25 of an inch has been collected, the vessel automatically empties itself, the pencil goes back to zero, and the record begins again.

At the Kew Observatory, Richmond, in the Old Deer Park, originally the private Observatory of King George III., and now a branch of the National Physical Laboratory (Observatory Department), in addition to important work in the testing of instruments, thermometers, barometers, chronometers, etc., for which the "Kew Observatory" certificates are desired, there have been going on for a long time continuous meteorological and magnetic observations, both with self-recording instruments, and by means of regular eye readings. The observations carried on at Kew, though to a great extent similar to those at Greenwich, have an independent value of their own, and whilst the testing of chronometers and watches forms a large part of the work at Greenwich, the staff at Kew, in addition to their regular scientific work, are more occupied with the testing of meteorological and magnetic instruments, and in the training of observers, who propose to work in remote regions. Here, as also at the Jermyn Street Museum, Piccadilly, is to be found a glycerine barometer, which, owing to the smaller density of glycerine as compared with mercury, has a much longer tube, so that slight variations in pressure give rise to greater movements of the glycerine column (in inverse proportion to the relative density of the two liquids). The specific gravity of glycerine being only 1·27, whilst that of mercury is 13·6, the former column will be more than ten times as long as the latter. Glycerine has the disadvantage, however, of solidifying at a higher temperature, and cannot easily be obtained as pure as the liquid metal.

Amongst other observatories, where systematic meteorological observations are carried out on a large scale, may be especially mentioned the great Observatory at Pawlowsk, in Russia, fitted with the most complete series of meteorological instruments in the world. A very detailed description of this institution has been given by Dr Waldo, in his well-known book, "Modern Meteorology." Of special interest from the nature of the observations of cloud phenomena and other features of the upper air are the mountain observatories, most of which are situated in the Alpine regions of Europe. In Switzerland, the Santis and Rigi stations; in Austria, the Sonnblick, the highest in Europe, 10,000 feet above sea-level; in Italy, the Observatory of Etna; in France, the Puy de Dôme; the observatory at the top of the Eiffel

Tower, Paris; and the observatory in America, at Mount Hamilton, California (especially famous for the Lick telescope and the wonderful series of astronomical observations made there), are amongst the best known of these stations. For some years a meteorological observatory was maintained on Ben Nevis, in Scotland, the highest of the British mountains; supported by a grant from the Government and the Royal Meteorological Society, but it has been since abandoned. The highest meteorological station in the world is probably that of El Misti, in Peru, containing a number of self-recording instruments, at the height of 19,000 feet above the sea, erected under the auspices of Harvard College (U.S.A.).

At most private astronomical observatories in this country there is to be found the installations of a second order station where observations are regularly carried on, whilst in a few (*e.g.*, Stonyhurst, Parsonstown, etc.) the hourly readings and self-registering instruments entitle these to be called rather first order stations. The regular instruments for a second order station are the following:—There must be a standard barometer (preferably of the Fortin pattern with movable cistern), with vernier and attached thermometer. Next there should be a pair of thermometers, wet and dry bulb respectively, whose readings should be regularly checked by comparison with standard instruments or in other well-known ways; also a maximum and a minimum thermometer. These instruments should be placed in a position where they are freely exposed to the air, but sheltered from sun, rain, and excessive wind. For this purpose they are usually placed in some kind of screen, of which Stevenson's well-known form seems to be on the whole the most generally suitable. The wet and dry bulb thermometers should be fastened to the wall of the screen, side by side, in an upright position, their bulbs being a little above the floor of the screen, whilst the other two thermometers should hang in a horizontal position within the screen, supported by hooks which fit into nails from the wall, so that they may be "set" after each reading. These instruments are usually at a height of about 4 feet from the ground. In addition there may be a black bulb thermometer for measuring "solar radiation," supported in a horizontal position in the open air on a kind of stand at about the same height as the other thermometers, and lastly a grass minimum thermometer, which is suspended on two wooden Y's at a height of 1 or 2 inches above the ground.

Next after the barometer and thermometers comes the rain gauge or gauges. These should be set up in a well-exposed position, and not near trees, walls, or other buildings. The height of the rim of the "ground" gauge should in general be about 1 foot. Upper gauges are sometimes placed on a roof or wall, and if compared with one upon the ground, it will be found that the amount collected will be less in the former case than in the latter.

For instance, at Markree, in Ireland, it was found that of two rain gauges, one 16½ feet above the ground and the other 6 inches from the surface, the amount registered by the former had to be multiplied by 1·2045 to reduce it to the level of the lower gauge. A total annual rainfall was 44·87 inches as recorded by the lower gauge, but only 37·25 inches in the upper one. This difference is probably due to local eddies caused by wall or roof, as the case may be, blowing some of the rain over the upper gauge instead of into it.

At most second order stations there is to be found a sunshine recorder, usually of the Campbell-Stokes' pattern, consisting of a glass globe which focusses the sun's rays upon a strip of cardboard graduated to correspond to the times of day when the solar image falls upon any point of it.

Three series of grooves and corresponding cards are in use, for summer, spring and autumn, and winter respectively, on account of the different altitude of the sun in the different seasons. The sunshine recorder has the disadvantage of not registering faint sunshine; when light clouds or haze are present between the sun and the instrument, the image is not strong enough to burn a trace on the paper. At some stations, however, the Jordan form of sunshine recorder is used instead. A trace due to the chemical action of the sunlight, of greater or less intensity, is made upon a sheet of sensitised paper placed in a dark chamber, into which light from the sun enters through two small apertures.

Records of the state and amount of cloudiness, force of wind, etc., are usually made by eye estimates without specific instruments, though a nephoscope is in use at larger institutions, and various forms of anemometers of greater or less degrees of reliability are to be met with.

The observations at stations of the second order should be made at least *twice* a day, and the hours of 9 A.M. and 9 P.M. (local time) have been chosen almost invariably by the volunteer observers throughout the United Kingdom. Other combinations, however, have been decided to be admissible, *e.g.*, 8 A.M., 2 P.M., and 8 P.M., but in general the combination of 9 A.M. and 9 P.M. is to be preferred, and it is found that "the means of these observations do not differ much from the true daily mean." At the morning observation hour (9 A.M.) the barometer, with its attached thermometer, is to be first read; the latter instrument first, as the warmth of the observer's body will cause a slight rise in its temperature.

In reading the barometer (if it is of the Fortin pattern, as is usually the case), the observer should be careful that the ivory point of the scale does not dip into the mercury, but just touches it, and the vernier should be set so that its lower edge just touches the convex surface of the mercury in the tube, as seen by the eye on a level with the front and back edge of the vernier and top of the mercury. It may be sometimes necessary to slightly tap the instrument to allow the "force of capillarity to exert its normal action" and prevent the mercury from sticking to the glass, and it will be found useful to place a piece of white paper behind the tube, so as to allow of setting the vernier accurately. Of course the instrument must hang *vertically*, and care should be taken to prevent the introduction of air bubbles, whose presence not only depresses the mercury column, but they also act chemically upon the liquid and corrode it. Next to the barometer the dry and wet bulb thermometers should be carefully read, and the water in the vessel, keeping the wet bulb damp, replenished if need be. These instruments are usually placed in a screen, together with the maximum and minimum thermometers, but these latter are not read till the evening observation. Distilled or rain water should always be used for the wet bulb, and the piece of muslin or worsted used to keep the latter damp should be changed every two or three weeks, or more often if exposed to a dusty atmosphere.

After this the rain gauge should be examined, and its contents poured into a graduated (glass) measure. It is the practice to read this instrument once a day, at the *morning observation*, and to enter the amount as having fallen on the *previous day*, inasmuch as in most circumstances more rain is likely to have fallen in the fifteen hours from 9 A.M. to midnight of the previous day, than in the nine hours from midnight to 9 A.M. A better practice would seem to be to read the rain gauge at 9 P.M., when there would be twenty-one hours of one day, and only three hours of the preceding day, but this is not done for reasons with which I am not clearly acquainted. However, at present the rain gauge *is* read at 9 A.M.

The direction of the wind, as given by the vane, is next to be recorded, as well as its estimated force on the Beaufort scale, an account of which has been given in a previous chapter. Direction should, of course, be always given according to true geographical and not *compass* bearings, though now that the magnetic north through variation is becoming every year nearer the true north (in this country) the error is a decreasing amount. Various forms of anemometers, of which the most frequently used is Robinson's, are to be met with in different observatories. Lind's and Dines' anemometers are also sometimes used, the latter, like Robinson's, measuring the wind velocity approximately in miles per hour. The theory of the Robinson anemometer was given by the inventor in 1850 (*Transactions of the Royal Irish Academy*), and he considered that the velocity of the centre of the four cups (four hemispherical cups of thin metal attached to the ends of two light rods crossing each at right angles form the essential features of the instrument. They are fastened to a vertical axis, and revolve under the influence of the wind, a registering apparatus giving the number of revolutions) must be multiplied by three to get the velocity of the wind; but later experiments and investigations by Stowe, Dines, and others, have shown that this factor is too large, and that the true multiplier should be from about 2·0 to 2·2 instead of 3 for moderate speeds. But the whole "theory and practice" of the anemometer is still very imperfect, and little reliance can be placed on estimates of the exact number of miles per hour registered for wind velocities in storms and gales. In recording the wind it is necessary to be sure that the true direction of the main wind passing over the station be entered, and not a mere local eddy. The amount and character of the clouds are to be registered for each observation. A clear blue sky is regarded as 0, and a completely overcast one is registered as 10, the observer estimating as carefully as possible the proportions of clear and cloudy sky. Lastly, the general character of the weather, since the last observation (of the previous evening) should be recorded.

The evening observations, like the morning ones, should commence with the reading of the barometer and its attached thermometer, which should be done as quickly, yet carefully, as possible. Artificial light will ordinarily be required for the evening observations, except at stations in the north of Scotland during summer, and an ordinary bull's-eye lantern will be found the best form of lamp. The barometer, of course, should be fixed in a position out of the reach of direct sunshine, and not exposed to sudden changes of temperature. After the barometer, the dry and wet bulb thermometers should be read, as in the morning observations, and this time the maximum and minimum thermometers. The readings of these latter should be put down to the day of observation (*unlike* those for the rain gauge, which are set down for the previous day). After being read, these latter instruments should be *set*, *i.e.*, the detached column of the maximum thermometer brought down to the main body of mercury, and the index of the minimum (Rutherford's form) brought to the top of the column of spirit. It is advisable to sometimes examine the latter, for occasionally a portion of the spirit becomes volatilised and condenses at the upper end of the tube; it must then be brought back to the main column by swinging the instrument briskly to and fro, holding it bulb downwards, till all the detached portion is united to the rest. Sometimes it may be necessary to *slightly* heat the detached portion to make it rejoin the rest of the liquid. Casella's *minimum* thermometer is also sometimes used, but is a very delicate instrument, and the liquid employed being mercury, it cannot be used for very low temperatures, though for such as are met with in these islands its readings are probably more accurate than those of a spirit thermometer. Alcohol, though it has the advantage of remaining liquid at the lowest temperatures, is not so regular in its expansion and contraction by heat or cold as mercury, is more volatile, and not so sensitive to sudden changes of temperature.

After the dry and wet bulb, maximum and minimum thermometers are read, and the latter set, the black bulb and grass minimum thermometers should next be examined, their readings taken, and these instruments then set also. Their readings are also to be entered for the same day as that of observation, like those of the maximum and minimum thermometers. Thus each of these instruments is only read once a day, in the evening, whilst the barometer and its attached thermometer, as well as the dry and wet bulb thermometers, are read twice daily. Lastly, the card of the sunshine recorder should be removed, and a new card put in for the following day. The trace can be measured at leisure, by comparing its length with the scale of hours marked upon the card, the date during which it was exposed being always written upon the card *immediately after its removal from the groove.* If this is not done, after a few days it will be difficult, if not impossible, to say on which day so much, or so little, bright sunshine was recorded. As in the morning, the direction and force of the wind, the form and amount of cloudiness, weather at time of observation, and its general character since the morning, should be recorded in the observer's rough note-book, before he has had time to forget or to confuse the weather of one day with that of another. An interesting task will be found in the comparison of the actually observed weather during any period at the observer's station with the general character of that predicted for his district by the "Daily Weather Report" issued by the Meteorological Office. Speaking only for his own observations, the author can testify that though a remarkable degree of accordance sometimes appears between predicted and recorded weather, the percentage of predictions of "complete" or "partial" successes always seemed less than that often claimed for these prognostics.

No doubt this arises from the difficulty of assigning and allowing for local variations of a more or less temporary character: when there may be heavy continuous rain in one station, there will only be a few slight showers in a neighbouring district; a storm on the exposed coast will only be felt as a moderate amount of wind a few miles inland, etc.

Moreover, the whole of the British Islands being divided into eleven districts, it frequently happens that very different weather prevails in different parts of one and the same meteorological district. For instance, district No. 5, "England, south London and Channel," covers a wide area, and it is no uncommon experience to find very different conditions prevailing even in different parts of London alone. On the other hand, especially in settled anticyclonic conditions, much the same kind of weather prevails over a whole continent for days at a time.

About fifty stations send daily telegraphic communications, and from the information thus supplied the weather charts are prepared and forecasts issued by the London office. It has been often pointed out that our own islands (and especially the western portions) are not well situated for the prediction of probable weather changes, and the issue of forecasts. The prevailing wind, south-west, comes to us from the ocean, over which no permanent stations exist, and though one sometimes hears of storms "telegraphed" from across the Atlantic, yet it must rarely happen that a cyclonic disturbance, even starting due eastward from North America, will travel without deviation in its course, and reach our shores. More often it will change in direction whilst passing over so great a distance, or may even fill up. On the Continent, in Germany and Central Europe generally, the conditions for successful forecasting are more favourable, since there are land stations both to the east and west whence they may receive information of coming changes, and the same is the case with the eastern states of North America.

A good many years ago a scheme was developed by the late Admiral Fitzroy, then Director of the Meteorological Office, for conveying storm warning to seaport towns. Telegraph information of storms in progress, which storms might be expected to travel to other districts, was received, and the news sent to the threatened districts as far as possible.

The signalling apparatus known as the "cone and drum" was set up in various prominent positions, and the references such as "N. cone flying in districts 2 and 3," etc., still appear in the daily "weather forecasts" published by the newspapers.

The signal apparatus consisted of a mast about 30 to 40 feet high, with cordage, a cone, a drum, and signal lanterns. Each cone and drum was made of a wooden frame covered with canvas, and their size was about 3 feet. When hoisted with its point upwards, the cone indicated that a gale from the north was to be expected; if its point was turned downwards, a southerly storm was coming. This was read north cone flying or south cone flying, as the case might be. The hoisting of the drum indicated that storms might be expected, but direction indefinite. The hoisting of both cone and drum indicated a violent storm, the position of the cone giving the probable direction. "These cautionary signals advert to winds during the next two or three days." The drum has been discontinued, but the cone is still hoisted from time to time, as occasion seems to warrant, and though opinion seems divided as to the utility of these warnings, still "it is better to warn a ship's captain erroneously of a storm which does not happen, than not to give him a warning of a storm which does come." However, Mr Chambers states that in 1894 as many as 92 per cent. of the warnings were followed by gales or strong winds, as against 87 per cent. in 1890 and 79 per cent. in 1885. Thus it would appear that accuracy in this respect is increasing.

The eleven districts into which the British Islands are now divided for "forecasting" purposes are as follows:—

District No.	District
0.	North Scotland (north of Caledonian Canal).
1.	East Scotland (south of Caledonian Canal, Aberdeen, Perth, Lothians, etc.).
2.	North-East England (Northumberland, Durham, Yorkshire, Lincolnshire).
3.	East England (East Anglia, Essex).
4.	Midland Counties (Bucks, Oxford, Warwick, Stafford, Derby, etc.).

District No.	District.
5.	England, South — London and Channel (Kent, Surrey, Sussex, Hampshire, etc.).
6.	West Scotland (south of Caledonian Canal, Argyll, Ayr, Galloway, etc.).
7.	North-West England (Cumberland, Westmorland, Lancashire, North Wales).
8.	South-West England (Devon, Cornwall, Somerset, South and Central Wales).
9.	North Ireland (Ulster, North Connaught, and North Leinster).
10.	South Ireland (rest of Ireland, south of latitude 53½° N.).

But two or more of these are often combined, and a smaller number of divisions is probably *in general* sufficient, so far as the accuracy of the forecasts at present goes, since only very *general* information can be given.

The Meteorological Office, London, at present issues daily and weekly weather reports. On the daily report (one sheet of four pages, price one penny, issued for 8 A.M. of each day) is given (page 1) the barometric pressure, temperature, direction and force of wind, and cloudiness, at over fifty stations in Scandinavia, France, Germany, and the British Isles (and occasionally one or two in Spain), for the previous evening and the morning of the day of issue, with the changes in pressure and temperature, the maximum and minimum temperatures during the past twenty-four hours, hours of sunshine and amount of rainfall, etc. On the second page are given charts giving the isobars at intervals of $\frac{1}{10}$th of an inch for the morning of issue, the temperature and other weather conditions, also a map showing the *average* rainfall and mean temperature during the same period as deduced from long continued observations. General remarks on the "situation" and possible changes are discussed on page 3, and the "forecasts" for the twenty-four hours, ending at noon the day following that of issue, are given. On the last page of the sheet additional observations, late reports for the previous day, etc., are entered.[1]

The *weekly weather* report, as its name indicates, gives on six pages or so a summary of the weather conditions over these islands and the greater part of Europe for the *past* week.

A summary of temperature, rainfall, and duration of bright sunshine in each of the eleven districts and the Channel Islands is first given, also comparisons with and differences from the mean values of these quantities and "general remarks." Next follow the data from which the summary has been calculated, the weekly reports from about eighty first and second order stations in the eleven districts. For each day during the week is given a chart of temperature and weather at 8 A.M., and barometer and wind at 8 A.M. and 6 P.M. respectively, with remarks on changes at foot of each chart. At the end, explanation of symbols, isobars, arrows to show

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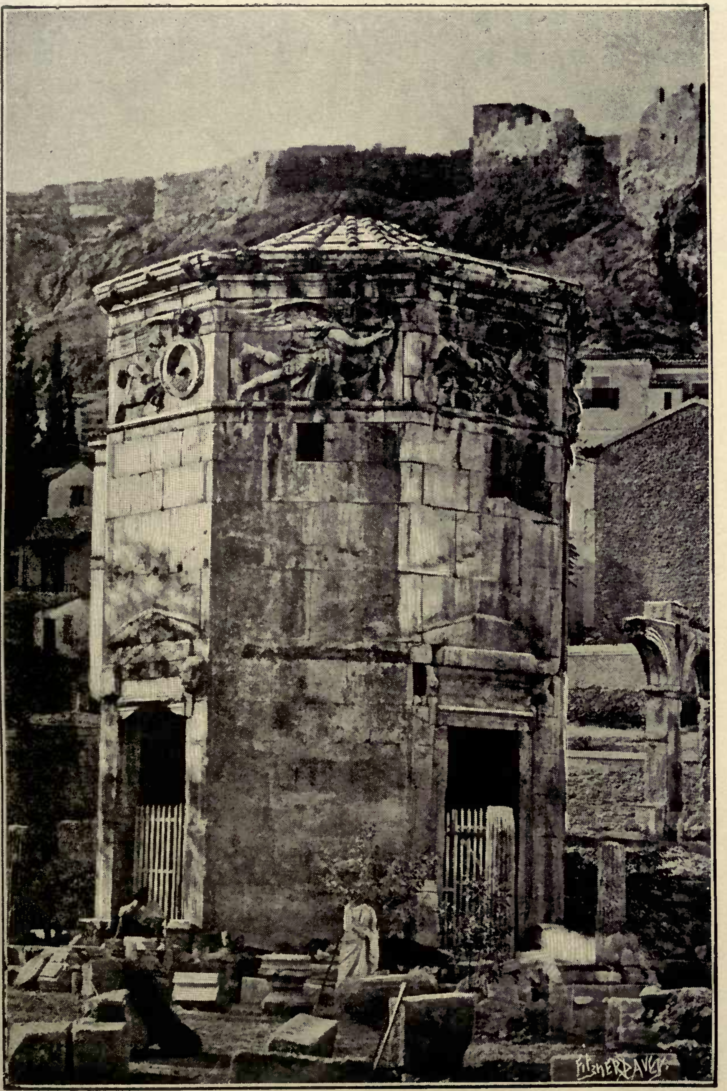
[1] From 1st January, 1911, some alteration has been made in the "Daily Weather Report." Pages 2 and 3 are recast, the maps enlarged, and additional information given. A new section, "London Observations," appears on page 4, in addition to the additional observations, radio telegraphic information from the Atlantic, etc.

the force of wind (thus ⊙ calm ⟶ light to moderate breeze, ⸜⟶ fresh to strong breeze, ≻⟶ gale, etc.), and the weather abbreviations used, *e.g.*, *b* = blue sky, *c* = detached clouds, *o* = overcast, *m* = misty, *f* = foggy, *q* = squally, *r* = rain, *h* = hail, *s* = snow, *l* = lightning, *t* = thunder. Isothermal lines show the distribution of temperature and diagonal lines = rough sea, etc., with shading proportional to the disturbance.

Note.—Although the records of temperature, pressure, etc., are commonly given in Fahrenheit degrees and "English" measure, many recent meteorological investigations are quoted in terms of the metric system and centigrade scale of temperatures, but the conversion from one to another is merely a matter of arithmetic. Though there seems a prejudice against such numbers as 15° for "temperate," 35° for "blood heat," etc., yet the advantage of a common scale, universally accepted and requiring no arithmetical manipulation to be at once available, is such that trifling difficulties of that kind will be soon got over. Greenwich time has been almost universally adopted, even recently by the French, so that it would be a graceful act on the part of British meteorologists to use the measures sometimes called "French," but which are not merely so, whose symmetry and uniformity contrast so strongly with the complexity of our "British" systems, the acquisition of a knowledge of which takes up so much of the schoolboy's time, most of which knowledge is soon forgotten afterwards.

Note.—By the kind permission of my friend, Mr Inwards, I give an illustration of the Temple of the Winds, Athens, which may perhaps be called the oldest meteorological observatory in the world. This building is a small marble octagonal tower, and was constructed about 100 B.C. At the centre of the roof was placed a wind-vane, the figure of a triton, whose "sceptre" always pointed to the "wind octant." The eight sides of this temple were built so as each to face one of these directions, and on each side was sculptured a human figure in relief, representing the character of a particular wind. The north wind is represented by a figure of a warmly-clad man clothed in furs, and blowing fiercely on a trumpet; the east wind is expressed by the figure of a young man with flowing hair; the west wind by the figure of a lightly-clad and beautiful youth, with his lap full of flowers. Each figure represented, "as far as a figure can, the character and qualities of the particular wind which it faces," and thus we have evidence that the character of the winds has not materially changed during the last two thousand years in Greece.



TEMPLE OF THE WINDS, ATHENS.
(By permission of R. Inwards, Esq., F.R.A.S.)

To face p. 260.

CHAPTER XIV

WEATHER SIGNS AND PORTENTS OF COMING CHANGES—SUN—MOON—CLOUDS — CIRRUS — CIRRO-STRATUS — CIRRO - CUMULUS — STRATUS —CUMULUS — CUMULO-STRATUS — COLOURS OF THE SKY — ANIMALS —BIRDS.

THE accumulated experience of centuries of observation has led to the discovery of certain rules and weather signs; a brief summary of a few of these may not be without interest. First and foremost we may put such as are associated with the appearance of the sun and moon; then come the clouds, whose form, density, and motion are so continually varying; and lastly, signs derived from the movements of animals, opening and closing of plants, etc. Of these we may remark that the influence and appearance of the sun has a very real bearing universally recognised, but the supposed changes of weather, due to changes of the moon, though widely believed in, "without rhyme or reason," rest on no basis of fact at all. In one sense the moon is never changing, in another it is always changing. The transition from "New Moon" to "First Quarter," etc., the varying appearance called the "change" of the moon, is a gradual phenomenon, and merely represents a greater or less amount of its illuminated surface turned towards us. The moon, being an opaque globe, shines only by reflected light from the sun, and the latter only lights up one hemisphere at a time, more or less of which is turned towards the earth at different times. Since the total amount of light given by the full moon to the earth is only about $\frac{1}{800,000}$th that of sunlight, and the heat is even more difficult to detect, any action must be of excessively small amount.

Moreover, the evidence of statistics is conclusive as to the absence of any connection between the moon's phases and the state of the weather, though some are of opinion that the full moon has a slight clearing effect on a cloudy sky. This is expressed by the saying: "The full moon eats clouds."

A red sky in the evening, followed by a grey sky in the morning, is generally regarded as a sign of fine weather, and conversely a grey sky at night, followed by red, lowering weather next morning, is considered a sign of coming rain. This opinion is expressed in the popular lines:—

> "Evening red and morning grey,
> Help the traveller on his way.
> Evening grey and morning red,
> Pour down rain upon his head."

The appearance of sun rays or streaks between the clouds indicates rain to follow soon, and is popularly called "the sun drawing water."

The appearance of halos round sun or moon furnishes a copious literature, and the popular idea is referred to by poets and others. Longfellow, in his *Wreck of the Hesperus*, makes a sailor say to the skipper:—

> "I pray thee put into yonder port
> For I fear a hurricane.
> Last night the moon had a golden ring,
> And to-night no moon we see!"

The greater or less distance of this halo or *corona* from the moon is supposed to indicate the less or greater time within which the rain will fall:—

> "Circle near, water far,
> Circle far, water near."

The size of the drops regulates the diameter. The colour of the sky towards sunset is a prognostic of wind. "A bright yellow sky at sunset presages wind" (Fitzroy). A pale yellow sky is a sign of wet:—

> "If the sun goes pale to bed,
> It will rain to-morrow, it is said."

This "watery" sun is a very common indication of the front part of a cyclone. "After the front part, where the sky gives a watery look to the sun, has passed over the observer, the rainy portion will also have to come over him."

Amongst imaginary signs which appear to have gained considerable credence, one knows not why or how, may be mentioned the "moon on her back," with horns pointing upwards, so often regarded as a presage of wet weather. The position of the moon's "horns" *entirely depends on her angular distance* from the sun, the line joining the points, or cusps, as they are called, being always perpendicular to the line joining sun and moon, and has consequently nothing whatsoever to do with *the weather*, being always definite and predictable beforehand. The moon's "changes" have an equally fictitious connection with weather changes. As we have said, in one sense the moon is always changing, the amount of *light* reflected by her towards the earth continuously increasing from new moon to full moon, and continuously decreasing from full moon to new moon again, but the *whole moon is always there*, so that apart from the slow change of distance we may say that the moon never changes! Since the total amount of light given us by the full moon does not exceed $\frac{1}{800,000}$th that of sunlight, we see how excessively small must be the effect of *changes* in so insignificant a quantity.

The moon, by its gravitative action, must produce a minute atmospheric tide analogous in kind to that produced by her in the waters of the ocean, but its *amount* is so *small* that even in tropical regions this "tide" is scarcely detectable, whilst in other parts of the world the smallest disturbance due to other causes completely masks it. Immense masses of statistics have been produced to show the want of connection between moon "changes" and weather changes, but the legend still lingers on, perhaps one justification of Carlyle's well-known classification of the population of these islands.

There is a very extensive literature of cloud lore. From the earliest ages to the present time the weather signs and warnings prevalent in all countries have been of great value in general, though occasions arise when the event belies the prognostic. Many references to cloud appearances occur in the Bible, both in the Old and New Testament: "A little cloud out of the sea like a man's hand," the forerunner of a storm. "When ye see a cloud rise out of the west, straightway ye say: There cometh a shower, and so it is" (St Luke xii. 54). Admiral Fitzroy's remarks (chap. vii.), already referred to, may be supplemented by similar quotations from the "Shepherd of Banbury," and other weather prophets. "The increase of cloud indicates rain," whilst conversely "cloudy mornings often change to clear evenings." The movements of upper clouds crossing the sun and stars in a direction different from that of the lower clouds and wind, foretell a change of wind, whilst in hot weather the appearance of two strata of clouds moving in different directions is a sign of coming thunder. The change of cirrus clouds in the windward to cirro-stratus is a sign of rain. The appearance of these loftiest clouds, after a continued spell of fine weather, is a very certain prognostic of coming change, though small groups scattered over the sky are often found with fairly settled weather conditions. "Long parallel bands in the direction of the wind indicate steady high winds to come." Howard remarks of cirrus clouds: "These clouds announce the east wind. If their under surface is level and their streaks pointing upwards, they indicate rain, if downwards, wind and dry weather." After a clear frost, long streaks of cirrus, with ends bending towards each other, and pointing to the north-east, are signs of a thaw and south-west wind. Cirrus clouds in detached tufts, "mare's tails," as they are sometimes called, are regarded as a sign of coming wind, which blows from the quarter towards which the "tails" have pointed. The cirro-stratus form of cloud, fish-shaped, or "very like a whale," if pointing east and west indicates rain; if north and south, more fine weather (Inwards).

"If clouds look as if scratched by a hen,
Get ready to reef your topsails then."

This is in accordance with the opinion that this form of cloud precedes winds and rains, and the approach of bad weather is inferred from its greater or less abundance. The wavy-formed cirro-stratus is a forerunner of heat and thunder.

The phenomena of coronæ, parhelia and paraselenæ ("mock suns" and "mock moons"), occur with this form of cloud owing to its great extent and evenness, with little depth (thickness), so that these phenomena come to be themselves regarded as indications of the type of weather experienced when cirro-stratus clouds are present.

The cirro-cumulus cloud is well known from its producing the appearance known as mackerel sky, whose prognostics are summarised in the lines :—

> "Mackerel sky, mackerel sky,
> Not long wet, nor yet long dry."

In connection with the cirrus "mare's tails" we have the nautical saying :—

> "Mackerel sky and mare's tails
> Make lofty ships carry low sails,"

thus being an indication of coming wind. Cirro-cumulus clouds at a considerable height often indicate thunderstorms in a few hours, or perhaps longer. "Before thunder cirro-cumulus clouds often appear in very dense and compact masses in close contact" (Inwards). If, on the other hand, the clouds are soft and delicate in outline, fine weather may result, lasting for some few days.

The stratus or "night" cloud, as it is sometimes called, from its usual formation towards evening and dissipation by sunrise, is usually regarded as a harbinger of fine weather—"there are few finer days in the year than when the morning breaks out through a disappearing stratus cloud." In calm weather some fog at a lower level usually persists till dissipated by the increasing heat of the sun, "ground fog," indeed, being a name often applied by Howard to low stratus clouds. The cumulus or "day" cloud, when high up, is said to show that south and south-west winds are near at hand. Before rain these clouds increase rapidly in size, sink, and become more irregular in shape; if, on the other hand, they become "smaller at sunset than they were at noon," fine weather may be expected. If they are formed to "leeward" during a strong wind, they indicate the approach of a calm with rain, if they become heaped up during a strong wind at sunset thunder may be expected in the night (Inwards). The edges being very white, and the clouds fleecy and dense, or thick and close towards the middle, whilst the sky around is blue, they are of a frosty coldness, and will speedily fall in hail, snow, or rain. Captain Wilson Barker, in his "Clouds and Weather," distinguishes five varieties of cumulus:—(1) the fine weather cumulus; (2) the roll cumulus, seen towards the close of stormy weather; (3) the squall cumulus, accompanied by rain, snow, thunder and lightning, etc., according to season; (4) pillar cumulus, a rare form seen only in equatorial regions ("the doldrums"); (5) shower cumulus, from which fine showers fall, but which is accompanied by little or no wind.

The cumulo-stratus—"the *cumulus*, as it were, changing into the *nimbus*" (Scott)—is thus a forerunner of rain or snow, according to the season. Large masses collecting in the north-east and south-west, with the wind east, then cold rain, or snow may be expected, the wind ultimately backing towards the north (Chambers).

The varying colours of the sky and of the clouds have also bearings on the probable future weather conditions. Admiral Fitzroy remarks: "A dark, gloomy, blue sky is windy, but a light, bright, blue sky indicates fine weather; when the sky is of a sickly-looking greenish hue, wind or rain may be expected." Unusual visibility of distant objects, the outlines of hills seen sharply defined, distant sounds distinctly heard, are usually regarded as signs of coming rain. Doors and windows creak, blind cords snap, and persons afflicted with rheumatics or with old wounds and sores complain of more than ordinary pains. Animals in general, whose very existence often depends on slight changes in the weather, are especially sensitive to and cognisant of approaching rain or storms long before we know of their coming by other indications. Some of the "signs" of rain given are no doubt the result of careful observation of the habits of the lower animals, but it is difficult to say what value is to be attached to such tokens as the following :—

> "When cats sneeze, it is a sign of rain!"
> "When dogs eat grass, it will be rainy!"

The latter habit is by some authorities stated to be a medicinal precaution on the part of our canine friends.

The flight of birds, far and wide in fine weather, short and staying near their nests in more uncertain conditions, has been alluded to, and in most cases may be considered a reliable indication of the goodness or badness of weather for the next few days.

A disturbed condition of the animal world generally, the huddling of sheep together, loud croaking of frogs, chattering of magpies, crows, sparrows, etc., are all well-known signs of coming rain. A cloudy, gloomy day is preferred by the angler, "fishes rising more than usual at the approach of a storm," though we are also told that "they are said (in some parts) not to bite so well before rain." Bees are also notoriously fine weather animals, not venturing out when it is likely to be rainy, in accordance with the lines :—

> "If bees stay at home,
> Rain will soon come.
> If they fly away,
> Fine will be the day."

Even more sensitive than animals, the plant world is full of weather prophets. We have the well-known pimpernel, or Ploughman's weather-glass, the sea-weed, whose hygroscopic properties are often made use of, sensitive plants whose leaves contract at the approach of rain, and countless other objects.

The opening and closing of the petals of the pimpernel "is better understood amongst the Bedfordshire labourers than the indications of any instrument." In fine weather it opens in the morning (usually from 7 to 8 A.M.) and closes in the afternoon (2 to 3 P.M.); if it closes earlier than usual, or fails to open in the morning, this may be regarded as a sure sign of approaching rain. "Closed is the pink-eyed pimpernel."

The leaves of many trees curl more or less when the air is damp. "When the down of the dandelion contracts, it is a sign of rain;" whilst we are told conversely, "When fine weather is to follow, chickweed expands its leaves boldly and fully."

CHAPTER XV

CYCLES OF WEATHER—BRÜCKNER'S INVESTIGATION—RAINFALL—WET AND DRY PERIODS—OSCILLATIONS OF MEAN PRESSURE AND TEMPERATURE — SUN-SPOTS AND THE WEATHER — SUN-SPOT "PERIOD": ITS IRREGULAR LENGTH—THE MOON.

THE recurrence of cycles of hot and cold years, years of unusual dryness or of excessive precipitation, has often been asserted, but it is only within the last twenty years or so that any definite scientific information has been obtained from the vast masses of material collected all over the globe.

Nearly three hundred years ago Lord Bacon expressed the opinion that every forty years the same kind of weather recurred, and gave forth aphorisms such as the following, based on a sort of instinctive appreciation of the law of averages:—"A serene autumn denotes a windy winter; a windy winter, a rainy spring; a rainy spring, a serene summer; a serene summer, a windy autumn," so that the air on the balance is seldom debtor to itself (Inwards, "Weather Wisdom"); but these and similar "saws" are more often honoured in the breach than in the observance. The recurrence of former periods of unusual cold (glacial epochs), and of intermediate times of more moderate temperature, is well established by geological observations, and theories as to their cause, intermission, and recurrence have been propounded by astronomers and geologists from time to time, none, however, receiving general support. Of more recent and immediate importance, however, is the question of annual fluctuations in temperature and rainfall now going on. In 1891 Professor Brückner published the results of his investigations from the records of over three hundred stations distributed throughout the five continents, for the period 1830-1885; in some cases for a much longer period (*e.g.*, the observations at Paris go back to the end of the seventeenth century). Dividing his results into five year periods, or lustra, he found that for Europe the years 1831-1840 were on the whole years of deficient rainfall; for the period 1841-1855 the amount of rain was in excess of the average; 1856-1870 was again a period of deficiency, and 1871-1885 one of excess. The other continents show similar results, but for Asia the deviation of individual lustra from the mean rainfall is greater than for other parts of the globe. In the driest period the rainfall is only about three-quarters its value in the wettest. This oscillation is general throughout the globe at the same time, so that a deficient supply in one continent is not counterbalanced by an excess in another. The variation in the level of inland seas, lakes, rivers, etc., also affords a measure of long period variations in rainfall, and Dr Brückner gave the average duration of such oscillation for the Caspian Sea as about thirty-five years. From records of the Alpine glaciers and lakes in Europe, ten lakes in North America, and twelve lakes in Asia, he found that in general the periods of high and low water occur simultaneously all over the world, and the average value of the time from one maximum or minimum to the following one to be about 35·6 years. The times of "minima," for a number of rivers and lakes examined by him, are as nearly as possible the times of dry and warm climate, whilst the maxima correspond with wet and cold weather.

Coming now to variations of temperature, Brückner computed "lustra means" for twenty-two regions, using also some data given by Köppen for twenty-nine districts, mainly in the Northern Hemisphere. He thus obtained the following periods of relative heat and cold for a century (1791-1890):—

Warm	period,	1791-1805.	Cold	period,	1836-1850.
Cold	„	1806-1820.	Warm	„	1851-1870.
Warm	„	1821-1835.	Cold	„	1871-1885.

The reality of these periods is accepted by many meteorologists, and they are accordingly known by the name of Brückner's hot or cold periods respectively. It must be confessed, however, that the actual excess or defect of temperature during any of these periods, as referred to the general mean for the whole time that observations have been made, is but small, and some portion of the material used by Brückner and Köppen gave indefinite results.

Brückner, using the materials given by Hann in his book ("Luftdruck in Europa"), has also gone into the question of periodic variations in barometric pressure. His results are summarised by Dr Waldo ("Modern Meteorology") as follows:—

For the dry period as compared with the rainy period there exists:—

(1) A deepening of the constant cyclone which the annual averages show for the North Atlantic.

(2) An increase of the high pressure which extends from the Azores to the interior of Russia (anti-cyclone).

(3) A deepening of the low pressure in the northern part of the Indian Ocean and China Sea (cyclone).

(4) A decrease of the high pressure over Siberia (anti-cyclone).

(5) A general increase in the amplitude of the yearly oscillation, which causes in the dry period in winter high pressure in Europe and Siberia, low pressure over

the North Atlantic, and in summer a relatively low pressure in Central and Western Europe and on the North Atlantic.

Thus each rainy period is accompanied by a diminution of the differences of pressure existing over different regions, and conversely a dry period accentuates these differences, both for the annual averages at different places and also for seasonal average at the same spot.

The oscillations of "ice periods," *i.e.*, the variations in the length of time when the rivers of Northern Europe and Asia are ice-bound, and the dates of their becoming free from ice in the spring, as well as the extended series of records giving the times of the grape harvest in Germany, Switzerland, and France for several centuries, have also been examined by Dr Brückner. By means of the latter he has found it possible thus to estimate the periods of unusual warmth or dryness and those of cold and wet for Central Europe during nearly five hundred years.

By making use of records of the occurrence of severe winters from a yet earlier date, it has been found, with a fair degree of probability, that an average period of about thirty-five years intervenes between one succession of excess or deficiency of warmth and the following one, and this period we have seen also appears in dealing with variations of rainfall, water level, and barometric pressure. Thus, after all, Bacon's guess as to the recurrence of weather after forty years seems not so far out.

Of another kind is the question of the connection between sun-spots and the weather. More than fifty years ago Hofrath Schwabe, of Dessau, who had long and carefully observed the surface of the sun through his telescope, showed that the dark markings on the solar surface are periodic in character, at times being large and numerous, at other times almost or quite absent from the disc, and that the average interval from one maximum to the next is about eleven years. This period is, however, only a rough approximation, being sometimes as long as sixteen years, at other times as short as eight years. There seems also some evidence of the existence of secondary maxima and minima superposed in the main course. The nature of these spots is even yet quite uncertain, though there is no doubt that many, if not most, of them are depressions of some kind or other. The presence of these dark markings of itself diminishes the total amount of sunlight received, but on the other hand their existence indicates a generally disturbed condition of the solar photosphere (or light-giving envelope), so that it is quite uncertain whether we receive more or less heat from the sun at the time of a sun-spot maximum. The difference in any case must be a very minute fraction of the whole amount.

Of a connection between the greater or less frequency of spots and their sudden appearance and disappearance with terrestrial magnetism there can be no doubt.

The irregular variations of the needle, known as magnetic storms, are almost invariably synchronous with outbursts on the solar surface. Brilliant exhibitions of the Aurora (Borealis or Australis) are also seen over wide areas. There is, in addition to these occasional and spasmodic apparitions, a more intimate connection between the general variations of magnetic intensity and the great or less spottedness of the sun. Lamont, in 1850, pointed out that the average daily movements of the magnetic needle have a period of about ten and a half years, and that the greatest of these diurnal oscillations from mean position happen at or near the times of sun-spot maxima. In addition to its general pointing north and south, the compass needle undergoes minute daily changes. From about 7 A.M. it travels westwards through a small angle till about 1 P.M., during the afternoon it returns eastward till about 10 P.M., and then remains quiet till the morning again, but in summer-time the needle begins to move again slightly westward to about midnight, and returns again eastwards before 7 A.M. (Thompson). The extent of these oscillations does not usually exceed about 10′ of arc, being slightly greater in summer than in winter, and the average extent of this oscillation increases and decreases with fair regularity during a period of about eleven years or so.

Attempts have been made by various investigators to ascertain any connection between sun-spots and any other terrestrial phenomena, but so far the verdict must be "not proven" (*see* also chap. xi.). Jelinek, in 1870, from all records of temperature available in Germany up to that time, "found the influence of sun-spots inappreciable," whilst Stone at the Cape and Dr Gould of Cordoba, in South America, considered that observations taken at their stations showed a distinct though slight *diminution* of temperature at the time of sun-spot maximum. On the other hand, Mr F. Chambers of Bombay, in a paper contributed to *Nature* during 1878, drew the conclusion from barometer observations between 1848-1876 that the sun is hottest when most spotted. The late Dr Meldrum of Mauritius, from a comparison between the number of cyclonic storms observed in the Indian Ocean and the "spottedness" of the sun, considered that the former were more frequent at the time of sun-spot maximum than at those of minima, but the evidence on which this conclusion rests is of a somewhat unsatisfactory character. Dr Meldrum, and later, Sir Norman Lockyer, have made comparisons of the rainfall at stations near the Indian Ocean, Cape of Good Hope, and in India, which they considered to be, on the whole, confirmatory of this connection. On the other hand, the results from American stations seem to indicate that on the whole somewhat less rain than usual falls during a sun-spot maximum. The matter was very thoroughly discussed by the late Mr Symons, the greatest authority on rainfall of his day, and he concluded that there was no certain evidence of any connection. Mr Maunder, of Greenwich Observatory, from an examination of Sir John Eliot's and Dr Meldrum's catalogues of cyclones in the Bay of Bengal and the Southern Indian Ocean, has found several striking instances of the recurrence of a "cyclone" (cyclonic storm) at the interval of the solar synodic rotation (about twenty-seven and a quarter days). Of one hundred and nine cyclones recorded, he finds one sequence of five cyclones following each other at the above-mentioned interval, and several other sequences of four, though in some cases an interval of two or more rotations occurred between one storm and the following. He points out, however, that though this evidence be sufficient to render probable a connection between this rotation period and the frequency of cyclones, it does not necessarily follow that these storms are directly connected with sun-spots. The latter phenomena are those most easily observed, but it does not therefore follow that "sun-spots are in themselves the most significant of solar phenomena." In any case, the relationship pointed out indicates the connection of an "interval" and not a period.

The late Professor Jevons and others have tried to deduce some relation between sun-spots and periods of commercial crises, arguing that if the former have any effect on temperature, frequency of storms, and rainfall, they must thus indirectly affect agriculture and the state of the crops, etc., but whilst there is still so much uncertainty as to the nature of the relationship between the more or less spotted condition of the sun's surface and terrestrial meteorology, we must regard all such attempts as premature.

In conclusion we may quote the words of Abercromby ("Weather," p. 325):—

> "It is no doubt a very tempting ideal to look at the sun as the prime mover of the atmosphere, and to endeavour to follow variations in the heat or energy of his action into their final products as wind or rain. But when we consider what the real nature of weather is, as revealed to us by means of synoptic charts, we see at once that, though undoubtedly an alteration in the sun's power would sooner or later be reflected in his results, any attempt to deduce one from the other directly must lead to disastrous failure."

The subject of lunar influence on the weather, so favourite an idea with many, needs little notice here; it is rightly called by the late Professor Young "a relic of ancient superstition."

It is next to impossible to say what difference of temperature is produced by the moon's heating action. The moon in one sense is always changing, in another always the same. In fact, in the words of the "poet," we may say :—

> "The moon and the weather
> Oft change together ;
> But change of the moon
> Does not change the weather."

M. Flammarion estimates that the heat reaching us from the moon only affects the temperature by twelve millionths of a degree, and the atmospheric tide in the barometric pressure by a few hundredths of an inch. Statistics and weather tables examined from time to time by various authorities all give negative results. It is somewhat curious, to say the least, that those who assert this action of the moon, microscopic as it must be, frequently ignore the real and undoubted influence of the sun, the prime mover in all terrestrial phenomena. If, however, we take the so-called "changes" of the moon, these occur once every seven or eight days, so that all changes of the weather must occur within three or four days one side or the other of these events, and it is not difficult to find a sufficient number occurring within a less time. Thus, *by ignoring all the rest*, it is easy to establish such a connection as is desired, and indeed almost any desired relation can be similarly arrived at.

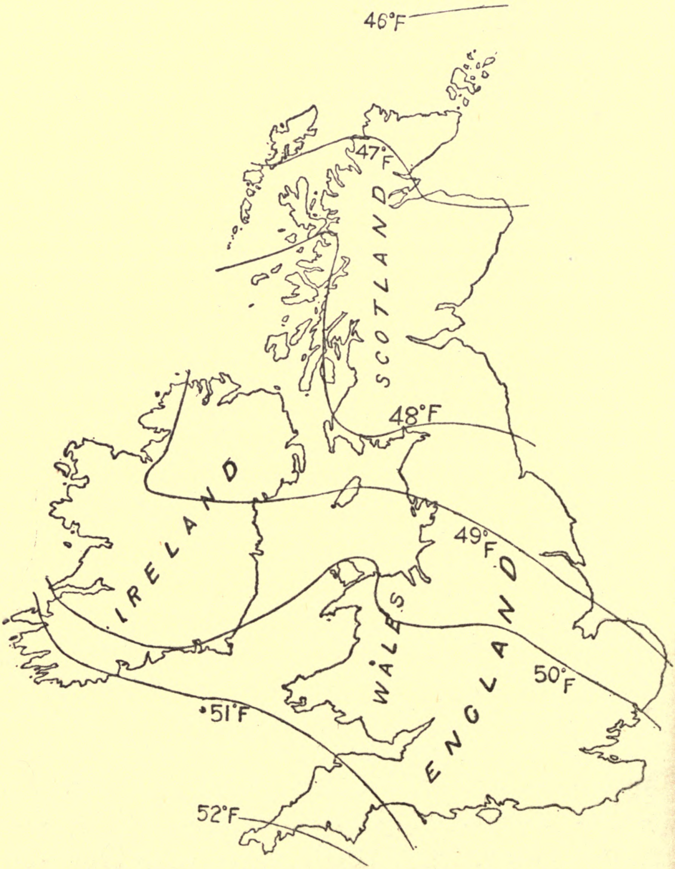
Mr Inwards, in his "Weather Fallacies," gives other lunar superstitions, such as—"Two full moons in one month cause a flood"; "It is a bad sign if the moon 'changes' on Saturday or Sunday," etc. Even the "halo" round the moon does not always precede rain, but this appearance, like that of the "old moon in the new moon's arms," stands on a higher level than the lunar superstitions, whilst no less an authority than Sir John Herschel believed that the full moon possessed a slight power of clearing away clouds. This has already been referred to in an earlier part of the present work.

Since the days when astrology was seriously studied, however, few have asserted any direct influence of the *planets* upon weather conditions, though the curious medieval idea that dew was a product of the stars may be even yet not extinct. One remembers, however, that some years ago a would-be "weather prophet" claimed to predict the future state of terrestrial weather from the position and motions of the planets Jupiter and Venus! When his predictions were not verified, he asserted that it was owing to the inaccuracy of Le Vernier's tables of those planets, upon which he had relied! Whether more *exact tables* enabled him to arrive at better results, I did not learn. But the words of Sir William Herschel, one hundred years ago, still hold good: "Prognostications of the weather are far above the knowledge of astronomers"; all that can yet be done is to offer probable "forecasts" for two or three days, sometimes less and sometimes more, ahead of date. But the mind of man seems so constituted that any speculation, however absurd, any guess, however random, will find supporters, and "fools rush in where angels fear to tread."

CHAPTER XVI

THE SEASONS—HEATING ACTION OF THE SUN—ZONES—CLIMATE AFFECTED BY PROXIMITY TO SEA—ISOTHERMAL LINES: THEIR COURSE ACROSS THE GLOBE—EXTREMES OF TEMPERATURE—ISABNORMALS—SEA TEMPERATURES—INFLUENCE OF GULF STREAM, ETC.—MINIMUM TEMPERATURE OF SEA.

THERE is probably no branch of meteorology more promising at the outset, yet more complex and disappointing in the sequel, than the study of the laws governing the motion of the atmosphere, and the attempt to infer from its present and past condition the probable future state of affairs at any given time. In this respect the science offers a remarkable contrast to the kindred one of astronomy. In the latter the accumulated observations of the past having led to the discovery of the simple law of gravitation, it has become possible by means of this single principle (combined with the laws of motion discovered experimentally by Galileo, and first stated in a definite form by Newton, to whom also the exact quantitative law of gravitation is due), to state with the utmost precision the past and future position of the sun and planets of the solar system through countless ages. On the other hand, it is a matter of common remark how frequently even



Mean Annual Isotherms for the British Isles. (After Buchan and Mill).

prognostics of weather made one day ahead fail signally, and it is probably impossible, even in the most settled conditions, to make forecasts as to their continuance, or otherwise, for more than two or three days, at least in our climate. Yet the laws which govern the motion of our atmospheric ocean, at the bottom of which we live and move and have our being, are known, and as definite as the law of gravity. The sun's heat and the rotation of the earth on its axis —the former the cause of the great atmospheric currents polewards and equatorwards respectively, the latter the agency producing the main deviation in their direction—are as regular and invariable as any known phenomena, though there is no doubt that in the course of ages both of these agencies are subject to change. Yet so far as the whole recorded history of mankind goes, there is no reason to suspect that the total amount of heat received annually by the earth from the sun has undergone any material change, nor has the period of rotation (length of day) changed so much as a second of time.

Theories as to the cause of former Ice Ages and warmer (interglacial) periods lie outside the range of meteorology, as is also the case with theories of tidal evolution, etc., based on supposed variations in the earth's rate of rotation in past and future ages. The only extra-terrestrial body of whose influence on the atmosphere we have undoubted proofs, is the sun, and this influence has not appreciably varied for thousands of years; for though in recent days, as we have seen, attempts have been made to connect the greater or less spottedness of the solar surface with variations in terrestrial atmospheric conditions, little or no positive evidence has yet been obtained of any such connection.

The sun's thermal influence, however, on the whole earth, atmosphere and all, is so preponderating and vital, that mankind have never been ignorant of the fact, and solar worship is the most rational form of superstition, still forming the basis of many creeds in civilised lands. In a material sense we are truly, as the ancient Peruvians called themselves, "the children of the sun."

> "The sun's rays," says Herschel ("Outlines of Astronomy," p. 399), "are the ultimate source of almost every motion that takes place on the surface of the earth. By its heat are produced all winds, and those disturbances in the electric equilibrium of the atmosphere which give rise to the phenomena of lightning, and probably also to those of terrestrial magnetism and the aurora. . . . By them the waters of the sea are made to circulate in vapour through the air and irrigate the land, producing springs and rivers. . . ."

With the exception of tidal action (itself partly due to the sun, but in a greater degree to the moon) and possible magnetic and electrical phenomena, the sun's heat is the exciting cause of almost all terrestrial motions. The moon, by its differential gravitative action upon the atmosphere and the solid earth, produces a minute atmospheric tide, causing a rise and fall of the mercurial barometer amounting to a few thousandths of an inch, and this, with the exception of a *possible* slight disturbance of terrestrial magnetism connected with its approach or recess at perigee and apogee respectively, is the only ascertained influence of that body on terrestrial weather conditions.

The variation in the amount of heat received from the sun at different times of the year produces the well-known phenomena of the seasons. In our latitude this variation (apart from the greater or less cloudiness of the sky), primarily arises from two main causes: (1) the greater or less altitude at which the sun is above the horizon; (2) the longer or shorter time he is above the horizon. In summer he ascends to a much greater height above the horizon, and his rays thus reach the surface more directly than in winter, when his altitude is less and the rays fall more obliquely. In the former case, too, the rays before reaching the surface have to pass through a less thickness of denser atmosphere than in the latter case, and it is especially the lower denser layers of the atmosphere (or rather the vapours thereof) that absorb much of the heat, allowing only a small portion to pass through. Moreover, the days in summer being longer than in winter, in our latitude, more heat is received from the sun during the day than is radiated away during the night, whilst the converse is the case in winter, when the days are shorter and the nights longer than in summer.

Thus the *general* course of the seasons—the cold of winter, the warmth of summer, and the intermediate conditions of spring and autumn—follows as a consequence of these variations in the amount of sunshine received. (In spring and autumn the sun's rays are *less oblique* than in winter, but not so direct as in summer, and the days are *longer* than the former, but *shorter* than those of the latter season, and so the temperature lies between those of the other periods.) In the same way in general the temperature of places nearer the Equator is higher than those further north and south; the polar regions, where the sun is often absent for months at a time, and never at any time high in the sky, are the coldest parts of the earth. Thus the familiar geographical division of the earth's surface into five zones, the Torrid Zone, the North and South Temperate Zones, the Arctic and the Antarctic Zones. Within the Torrid Zone, 23½° N. to 23½° S. latitude, which is bisected by the Equator, the sun is vertical at some time or other over every point, and its noonday altitude is never less than 43°. It is above the horizon at all places for some time every day for a period never greater than thirteen and a half hours or less than ten and a half hours, so that day and night are never of very varying lengths. On 21st March and 23rd September the day and night are theoretically everywhere of equal length, whence the name of "equinoxes" (Latin: *equus*, equal; *nox*, night; *i.e.*, night equal to day); at these times the sun is in the celestial Equator and is vertical at noon to all places on the terrestrial Equator. *Practically*, owing to the effect of the atmospheric refraction raising the sun's image above the horizon when it would otherwise be below, and causing twilight (a comparatively brief phenomenon in the tropical regions as compared to its duration in our latitudes), at these times the day is longer than the night.

Here the greatest amount of sunlight is received, and consequently the name of Torrid Zone is given to this part of the earth which the ancient Greeks thought was too hot to be inhabited by human beings.

On either side of the Torrid Zone there is (1) the North Temperate Zone; (2) the South Temperate Zone. Each of these zones extends from 23½° to 66½° of latitude. Within these zones the sun is never vertical, but attains his greatest altitude above the horizon at noon at the summer solstice. For the Northern Hemisphere this is on 21st June; for the Southern, 21st December. The limiting latitudes, 23½° N. and 23½° S. respectively, bounding the Torrid and either temperate zones, are known by the names of the Tropics of Cancer and of Capricorn respectively, for at the time when the sun is said technically to enter the sign of Cancer, he is vertical at noon at latitude 23½° N. (Tropic of Cancer) and begins his march southwards (Greek: τρέπω, *trepo*, I turn), whilst on 21st December he is said to enter the sign Capricorn, and returns once more northward. Within the temperate zones the length of time the sun is above the horizon varies greatly according to the season of the year and the latitude of the place, but everywhere he rises and sets at least once in the twenty-four hours. At either tropic the sun is vertical at noon for one day in the year, at other times the meridian altitude is less than this. At the northern and southern limits of the temperate zones, latitudes 66½° N. and 66½° S. respectively, which are correspondingly known as the Arctic and Antarctic Circles, the sun will theoretically be just on the horizon at the winter solstice of each hemisphere; practically, owing to refraction, he will be slightly above that circle. Thus in latitude 66½° N. on 21st December the sun will not rise at all, and the length of the night will be twenty-four hours, and the same thing will be the case for latitude 66½° S. on 21st June. Conversely at the summer solstice of either hemisphere he will not set at all, but just skirt the horizon at "midnight," and the phenomenon of the midnight sun may be seen. In higher latitudes, from 66½° N. to the North Pole and 66½° S. to the South Pole, the Frigid Zones, there will be periods during which the sun will never set, but describe almost complete circles in the sky, having its greatest altitude at "noon" and least at "midnight," in the Northern Hemisphere, when due south and due north respectively, whilst at other times of the year the sun will never rise. Thus, in Lapland, Greenland, etc., there will be several weeks of perpetual day during the summer-time, and several weeks of perpetual night during the winter, whilst, for the rest of the year the sun will rise and set daily, but the length of the day will vary from a few minutes to nearly twenty-four hours, and conversely with the night. At the poles the sun will be above the horizon for about six months at a time (rather longer, through the effect of refraction), its altitude varying with extreme slowness, so that for one day we may regard it as moving in a circle parallel to the horizon (*parallel* sphere). (*See* also chap. i.)

Nevertheless, though thus continuously visible in the polar regions, the small altitude above the horizon, never more than 23½° at the summer solstice at either pole, or 47°, its maximum value at noon on the Arctic Circle (21st June) or the Antarctic Circle (21st December), prevents the total amount of heat received by these regions even in summer from being so much as in lower latitudes. This theoretical and general distribution of temperature throughout the globe is, however, only a rough approximation to the truth. Owing to the fact that seven-tenths of the earth's surface is covered by water, whose behaviour under the influence of heat is very different from that of the solid land, the actual temperature of different places is enormously influenced by their greater or less proximity to large masses of water. Water of all ordinary substances[1] is the one whose specific heat is greatest, *i.e.*, a greater amount of heat is required to raise a given mass of it through any temperature than is required to raise an equal mass of another substance through the same range of temperature. Thus thirty times as much heat is required to raise a pound of water through 10°, say from 40° to 50°, as is required to raise a pound of mercury from 40° to 50°. In consequence of this, sudden increases or decreases in the amount of heat received are much slower in affecting the temperature of the sea than of the land.

In summer the heat of the sun gradually

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[1] A mixture of alcohol and water in certain proportions is said to have a somewhat greater specific heat than water; but this is not a "common" substance.

warms up the water in the daytime, but more slowly than the land, owing to the greater specific heat of the former; whilst this heat is not radiated away again by the water during the night with anything like the same quickness as is the case with that received by the land, also in winter again the sea surface is not cooled so much as the land masses. Thus the neighbourhood of the sea keeps the land masses cooler than they otherwise would be in summer, and warmer than would otherwise be the case in winter. This is strikingly shown (though there are other causes also at work to be mentioned directly) in comparing the climates of the British Islands and Central Russia. The latitude of Edinburgh (55° 55′ N.) is almost the same as that of Moscow (55° 45′ N.), so that both places receive directly almost exactly the same total amount of heat from the sun annually. Yet how different are their climates! The mean temperature of the former in January (the coldest month) is considerably above the freezing-point, at the latter far below that temperature, whilst in July (hottest month) the mean temperature at Edinburgh is under 60° F., at Moscow it is nearly 70°. The proximity of our islands to the Atlantic Ocean prevents the winter temperature from falling so low, and hinders the summer temperature from rising so high, as with a region so remote from the ocean as Central Russia. In summer the land masses impart some of their extra heat to the sea; in winter the sea in its turn gives up some of its heat to the land.

Another cause, and one of great importance to us as inhabitants of these islands, tending to the modification of temperature conditions, is the existence of ocean currents. (*See* also chap. x.) The intensely heated waters of the Gulf of Mexico give rise to the warm current of the Gulf Stream, which, flowing northwards and eastwards into the Atlantic, travels polewards almost as far as the latitude of the Arctic Circle, thereby raising the temperature of the British Islands and Western Europe generally. On the other hand, the cold current flowing from polar regions southwards renders the shores of Labrador, whose latitude is scarcely greater than that of Great Britain, ice-bound for most part of the year.

By long continued observations of the temperature at different places throughout the world, mean values of this element for the whole year and for separate months have been obtained, and curves called *isothermal lines* (ἴσος, equal; θέρμη, heat) have been drawn.

The idea of representing the distribution of temperature in this way is due to the great philosopher and traveller, Alexander von Humboldt, and charts showing the mean temperature of the whole globe for the year, as also for the months of January and July, are to be found in many works. A very detailed account of the course of these curves is to be found in Scott's "Meteorology" (chap. xii.). Speaking in a very general sense, the main feature of most of these curves for the Northern Hemisphere is the remarkable fall in temperature in crossing the continental mass of Europe and "Asia eastwards, its rise again on approaching and crossing the Pacific Ocean, and fall once more in crossing North America."

Taking one northern isothermal line as an example, say that of 50° F. or 10° C. (commencing with Europe), we find it crossing the centre of Ireland. Rising over the sea and dipping slightly in going over England, it enters the continent of Europe in North Germany; thence it runs south-eastwards, crosses Austria and South Russia, then touches the Caspian and Aral Seas at their northern extremities. It thence passes Lake Balkash, the Thian Shan Mountains, and Southern Mongolia, finally crossing the Japan Sea in latitude 40°. Thus in crossing the Eurasian continent its latitude has fallen from 55° to 40°. It next crosses the Pacific, its position becoming gradually more northerly, and enters America from Vancouver Island, latitude 50°. Crossing the American continent it again dips southward, crossing the great lakes at about latitude 43°, after which it rises again slightly, and enters the Atlantic in latitude 46°, just south of Newfoundland. During its course across the ocean it works its way gradually more northwards till it comes once more to the centre of Ireland (latitude 53°), where we started with it.

The isothermal lines for the Southern Hemisphere show similar dips when passing over continents, districts near the sea being generally warmer than places of the same latitude further inland; but owing to the much greater extent of water south of the Equator, the general course of these isotherms is more regular than for the opposite hemisphere. The isothermal line of 50° F. or 10° C. in the Southern Hemisphere runs almost along the parallel of 42° S. latitude, dipping only slightly below this in crossing part of the Southern Pacific and Patagonia. Curiously enough, the isothermal line of 40° F.,—whose course is almost entirely over the ocean, only touching the southern portion of Patagonia—is somewhat more irregular than that of 50° F., running from latitude 45° S. in the Indian Ocean south of Africa (longitude 30° E.) to latitude 53° S. in the South Pacific, a range of about 8° in latitude, whilst the isotherm of 50° F. does not vary more than about 5° in latitude from 40° S. latitude in the (South) Indian Ocean to 45° S. latitude in part of the Southern Pacific. But the range of the northern isothermals is vastly greater than this. By a comparison of the positions of the isothermal lines for the same temperature in the two hemispheres we find that on the whole, especially in high latitudes, the Northern Hemisphere is colder than the Southern.

There are, however, other considerations, besides the study of the course of the *mean* annual lines of temperature, which are of importance in giving us an idea as to the climate of any locality. Many places have the same or nearly the same annual mean temperature, whose summer and winter extremes are very different. To take an extreme instance, the average range of temperature difference between winter and summer in these islands is only about 20°, whilst in Verkhoyansk in Siberia, which has an unenviable notoriety as being the coldest place on the globe, this range amounts to no less than 100°. The July temperature of this place is about 60° (within 1° of that of Dublin) whilst the mean January temperature is −40°, the freezing-point of mercury. At times the thermometer (of course a spirit one must be used here) reads much lower,—80° having been recorded, whilst in summer the temperature has risen to that of blood heat. Thus between the extremes of −80° and + 96° we have a range of 176°, nearly equal to that between the freezing and boiling points of water, the "mean" range being, as we have stated, about 120°. Such a climate must cause a great strain on the powers of human endurance, and will hardly be recommended to the delicate invalid. We have here the most extreme case of "continental" as opposed to "insular" climate. Even within our own islands, however, there is a considerable variety in respect to "insular" climate. The excessive rainfall of the west of Ireland and the lake district of Cumberland, as contrasted with the dryness of Leinster and the eastern counties of England (Lincolnshire, etc.), the warmth of Devon and Cornwall, and the cold of the northern and eastern districts, are well-known examples within a limited area, showing how much the general character of climate is affected by purely local considerations.

The late Professor Dove, whose isothermal charts were amongst the earliest published, conceived the idea of representing the great contrasts prevailing between climates of places in the same latitude. He calculated for each month the normal temperature of each tenth degree of latitude, *i.e.*, that which it would have if its actual temperature were uniformly arranged, and we take from Mr Scott's book Hann's corrected values of his numbers, in Fahrenheit degrees, for the mean of the year:—

Lat.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
N.	79·7°	79·9°	77·5°	69·8°	56·5°	42·4°	29·8°	16·0°	6·8°	2·3°
S.	79·8°	78·0°	74·1°	69·9°	55·4°	43·7°	32·5°	...	...	...

By comparison of the actually existing temperatures at various places with the mean values for the respective latitudes, Dove drew a series of curves representing what he called the "thermic anomaly" of each month, calling the curves by the name of *isabnormals.* Just as places on the same *isothermal* have the same temperature, so places on the same *isabnormal* have temperatures deviating by an equal number of degrees from that calculated for their latitude. We find from these curves that in January almost the whole of Asia is below the normal value, whilst in Eastern Siberia, round Verkhoyansk, the deviation is as much as 40° F. On the other hand, our own islands, as was to be expected, have temperatures much above the normal corresponding to their latitude, whilst in Iceland and the west of Scandinavia the excess amounts to as much as 40°. Thus we see the negative anomaly of Eastern Siberia runs up to 40°, whilst the positive anomaly of Iceland and the surrounding sea is as much in the opposite direction. The isabnormals for July (summer of Northern Hemisphere and winter of Southern) all show much less deviation from normal conditions, but here the heating of continental masses and the cooling effect of the ocean are still sufficiently manifest. Recent work on this subject by Eredia and Naccari with regard to the isabnormals of Italy, by Gheorghin on the Balkan Peninsula, etc., all bring out the important influence of the waters of the sea in modifying the conditions of temperature and pressure over land masses. Even the Mediterranean, small though its size is in comparison with the great oceans, produces a measurable effect.

Of extreme temperatures experienced, though on the whole the equatorial regions are the hottest and the polar the coldest, yet actually on special occasions higher and lower temperatures than those experienced at the Equator and "nearest the Pole" are recorded elsewhere. In the centre of the Sahara the temperature occasionally mounts to 130° F., at Jacobabad, in the Sind desert, 120° has been recorded, both these districts being considerably north of the Equator, whilst in South Africa and Central Australia as great heat has been at times experienced. In London the highest summer shade temperature does not often exceed 95° F.

On the other hand, as already stated, at Verkhoyansk, a village in Eastern Siberia (latitude 68° N.), "the coldest inhabited place on the globe," the thermometer has been known to descend to −81° (1871), whilst during an Arctic expedition Captain Nares "once saw the thermometer descend to 84° F. below zero." The *mean* temperature of the Siberian town is, however, higher than that of the Arctic Seas, though the winter cold is greater.

It has been calculated by Ferrel that if the surface of the earth were entirely dry land and no transference of heat by ocean and atmospheric currents occurred, the temperature at the Equator would be about 131° F., that at the

Pole –108°. As given already, Professor Hann's corrected values of Dove's figures are for these +80° and +2° respectively for latitudes 0° (Equator) and 90° (Pole). Thus the circulation produced by wind and ocean currents lowers the temperature of the equatorial region by about 51°, and raises that of the polar regions by twice that amount, so rendering the whole earth habitable. It has been calculated that without an atmosphere the temperature even at the Equator would be –94° F., whilst at the Poles the thermometer would descend to –328° (Archibald); but these figures, though somewhat startling, can scarcely be said to have any meaning, except to suggest the possible extreme temperatures on an airless globe such as the moon is considered to be.

In the most general sense, all meteorological phenomena depending ultimately on the action of the sun's rays upon the various constituents of the atmosphere, it is evident that a study of the laws of the conduction and radiation of this heat, and the motions (of matter) thereby following, is of the utmost importance in our subject.

Thus the warm currents from the Equator towards the Poles, the colder polar currents flowing in to take their places, follow from the primary difference in the amount of heat received by each region respectively. The air at the Equator being heated more than that at the

Poles will expand more than the latter, and thus a change in the isobaric surfaces, or surfaces of equal pressure, will be produced, causing a flow towards the colder regions. Just as in a tank of water heated at one end the heated fluid will expand and tend to rise to a higher level than at the colder end, the difference of level will at once start a motion of the upper heated layers towards the further end of the tank, so, too, the air in the upper atmosphere will tend towards the polar regions. This flow will diminish the pressure on the surface, and so a current of air will come *along* the surface helping to restore the former equilibrium of pressure. Thus we get vertical *ascending* currents at the Equator, *descending* ones at the Poles, and intermediate regions of no motion.

Owing to the earth's rotation on its axis, the equatorial air going polewards and the polar air going equatorwards are *deviated*, whilst the distribution of land and water, the annual (apparent) motion of the sun northwards and southwards, causing somewhat different regions to be the most highly heated, and countless other minor modifying causes, all come into play.

We have already roughly sketched the distribution of temperature on the land surfaces as determined primarily by the amount of sun-heat directly received, and modified by the action of winds and the greater or less proximity of the seas, with their various warm and cold currents; it now remains to make a few remarks with regard to the temperatures prevailing over the sea itself. So far, though of recent years a good deal of information has been acquired as to temperatures below the surface, and a few observations at great depths have been made, most of our knowledge relates to that prevailing at the surface itself.

In general, both the diurnal and the annual range of temperature at sea are smaller than for places on land, in corresponding latitudes. The difference between winter and summer temperatures are, however, easily noticeable for all localities outside the tropics, being, as was to be expected, more perceptible for inland seas and regions of the ocean nearest the land than for the open sea, far from influence of land masses.

The range of temperature has its maximum and minimum values in general about one month later than on land; on the latter, February and August are considered the coldest and the hottest months, whilst on the sea the "annual extremes of heat and cold occur in the months of March and September" (Maury). On land the solid parts of the earth receive from the sun more heat (during the summer of each hemisphere respectively) by day than they radiate by night, and thus even after the maximum amount of heat is received (summer solstice) the gain by day exceeds the loss by night, and the temperature still rises for some time longer. So in our hemisphere the highest temperatures prevail in August and the latter part of July. At sea, owing to the greater specific heat of water over that of solid land, both rises and falls of temperature occur more gradually. Thus the waters continue to grow warmer even after the land temperatures have begun to fall, and the highest temperature comes in September, the lowest in March (in the Northern Hemisphere).

On a few occasions, at places near the Equator, temperatures of 90° F. have been observed at the sea surface, but in general the sea temperature seldom rises much above 80° F. in the Central Atlantic and Pacific, and the northern parts of the Indian Ocean.

The northern isotherm of 80° during the month of March runs across the Atlantic from the Caribbean Sea towards Africa, with a slight southward trend, its position varying from latitude 15° N. to the Equator (in longitude 22° W.), arriving near Cape Palmas, in Guinea, in about latitude 5° N. In September its course over the same ocean is much more sinuous. Starting from latitude 35° N., it runs westwards as far as longitude 40° W., after which it dips sharply southwards, reaches the Equator in longitude 26°, and then runs back again to the South American coast, slightly to the south of the Equator. The southern isotherms of 80°

for September and March follow very different tracks. The former, starting from the African coast near the River Gambia, runs a short way westwards, then dips southward at longitude 20° and returns to Africa in latitude 3° S., north of Loango in the Congo. The latter (southern isotherm of 80° for March), starting near Rio de Janeiro, runs with a northward trend towards Africa, making one or two southward dips on its way, and arrives in latitude 12° S., not far from Benguela. It attains its extreme northern position in the ocean (latitude 6° S.) at about 2° E. longitude (almost due south of Dahomey). The isothermals for 70° run courses much more nearly parallel to one another. Though somewhat closer together in position near the American coast than on the other side, the windings of the one follow very closely the convolutions of the other, so that by a shift of 20° in latitude, either may be obtained from the other. The March isotherm runs across the Atlantic (eastwards) with a general southerly trend, arriving off the African coast in latitude 17° N. (not far from Cape Verde); the September isotherm touches the coast of Southern Portugal (latitude 38° N.).

The influence of the Gulf Stream upon the course of the isotherms for lower temperatures is very strikingly shown. For instance, in the North Atlantic the northern branch of 50° isothermal (in March), starting from just below the latitude of New York (38° N.), runs eastwards and northwards past the shores of Nova Scotia and Newfoundland, thence towards Europe continually northwards till it reaches the latitude of 56° N. in longitude 17° W.; after which it bends slightly southwards and reaches these islands near the south of Ireland. The course of the isotherm for 60° in September is not very dissimilar from that of the isotherm for 50° in March, but it starts at a somewhat higher latitude (42° N.), not far from Cape Cod, and does not rise further than latitude 53° N. (in longitude 30° W.), arriving rather to the southward of the former's March position in Cornwall.

In the Southern Hemisphere the isotherm of 60° never deviates far from latitude 40° S. during its March course, and this very closely corresponds to the September isotherm of 50° in the same hemisphere. The March and September southern isotherms of 60° do not vary much from parallelism during their course over the Atlantic, the mean position of the former being in latitude 40° S., that of the latter about latitude 35° S. Neither of these vary in latitude so much as 5° north or south of their mean position, a great contrast to the course of the isotherms for the corresponding temperatures in the North Atlantic, whose variations are more than double that amount, and whose extreme limits of latitude differ by over 20° (*e.g.*, the March isotherm of 50° F. = 10° C.

is as far as 57° N. in longitude 17° W., and only 37° N. in longitude 73° W., whilst the variations of the September isotherm of 60° F. are of a slightly smaller range in latitude). The great northward trend of the North Atlantic isotherms strongly marks the influence of the warm "river in the ocean," whilst the absence of any similarly marked agency in the southern ones is shown by their closer coincidence with the latitude parallels. The smaller number of observations of sea temperature in the Pacific prevents any beyond very general inferences from being drawn from the course of the isotherms, but the influences of the seasonal changes of declination of the sun, as well as the special action of the ocean currents, are known to produce displacements corresponding to the former, and bendings in their course through the action of the latter. But the effect of currents is probably greater in the north temperate zone of the Atlantic than elsewhere, since the warm current of the Gulf Stream and the cold currents from the Arctic can more easily pass in and out, whereas in the Northern Pacific the warm current of the "Kuro Siwo" cannot easily pass out nor the colder waters of the Arctic enter through the narrow and shallow Behring Straits separating the Asiatic and American continents.

It was at one time supposed that since the temperature of maximum density for fresh water is about 39°·2 F. (4° C.) this temperature would be found to prevail at great depths all over the world, but it has since been shown as a result of the "Challenger" expeditions as well as by others also, that a lower temperature than this is met with. "In all latitudes where soundings were made, a temperature of about 32° prevailed in the depths of the sea."

CHAPTER XVII

UPPER AIR—BALLOON ASCENTS—KITES—ISOTHERMAL LAYER—DIVISION OF AIR INTO TWO REGIONS, LOWER AND UPPER.

Of recent years our knowledge of the conditions of the upper air has been increased by the results of balloon and kite ascents, and information has been obtained by means of self-recording instruments of the pressure and temperature prevailing up to a height of about 20 miles from the surface. Though it is true that we live at the "bottom of the vast atmospheric ocean" enveloping our globe, and writers have been fond of comparing our position to that of fishes at the bottom of the sea, yet there is but little real analogy in the two cases.

At the bottom of the sea the density is but slightly greater than that at the top, owing to the slight compressibility of water; no light can penetrate, and the most violent movements at the surface have no effect. On the other hand, the air, though reaching to an unknown height above the surface, decreases so rapidly in density upwards that at an altitude of 3 to 4 miles above the surface we have passed through half its mass, and the quantity above 20 miles from the surface must be a very small fraction of the whole, and be of insignificant density. The highest clouds are not often formed at an altitude of more than 5 or 6 miles, though occasionally a few are found at greater heights, and the quantity of water vapour must be exceedingly small even at the height of the highest mountains. The experiments of Tyndall, and more recently those of other physicists in this country and on the continent, have shown that the oxygen and nitrogen of the air have almost no absorbent action upon the solar rays, the latter passing through them almost as readily as through a vacuum, but carbon dioxide and water vapour, on the other hand, exercise so considerable an absorption that the amount lost even when the sun *is vertical* is not less than 30 per cent. of the whole, and a much greater proportion when the sun is nearer the horizon. Langley estimated that an even greater amount than this is absorbed, the more refrangible shorter waves being absorbed to a far larger extent than the others, so that if we could see the sun as it really is, it would be of what we call a "bluish" colour. *All* of this absorbed heat, however, is not lost to us, for though a part is radiated outwards, another portion is sent downwards (from the clouds, etc.), and warms the surface of the ground and the lower air.

More than a hundred years ago the brothers Montgolfier, by filling a silk or paper bag with hot air, caused the latter to ascend, and sent up sheep and fowls. Lichtenberg filled his balloon with hydrogen, and Pilatre de Rozier was the first person to make an ascent himself. His balloon was filled with hot air, not hydrogen, for it was found that the latter substance, though lighter, readily escaped through the pores of the paper. In later times coal gas has been generally used, from its cheapness and the ease with which it can be obtained. Many other ascents by Tissandier, Gay Lussac, Blanchard, Green, Welsh, etc., have been made since the time of the Montgolfiers, and the history of ballooning is full of terrible catastrophes and hair-breadth escapes, just as is the history of aeroplanes in our own day. The most interesting of those ascents from our point of view was the memorable series of balloon voyages made by Messrs Glaisher and Coxwell, who in 1862 reached an altitude which has never since been attained by *human* beings, rising to an elevation of nearly 37,000 feet, 7,000 feet above the level of the highest mountain.

The story is oft told how Mr Glaisher fainted, and his companion only managed to open the gas valve by means of his teeth, the cold being so great and the air pressure so low, estimated at equal to 7 inches of mercury (less than one quarter its value at the surface) whilst the temperature was far below the freezing-point of water, though the ascent was made in the summer-time. By this and other ascents there was established an approximate rate of decrease of temperature upwards. A few of Mr Glaisher's averages are given below (Deschanel, "Physics," vol. ii.) :—

Height above surface.	Rate of decrease of temperature upwards. With clear sky.	With cloudy sky.
From 0 to 1,000 ft.	1° F. in 139 ft.	1° F. in 222 ft.
„ 0 to 10,000 „	1° F. in 288 „	1° F. in 331 „
„ 0 to 20,000 „	1° F. in 365 „	1° F. in 468 „

This table shows also the effect of clouds in diminishing this rate of fall, it being necessary to go about one-third higher in a cloudy atmosphere to produce the same fall of temperature as when the sky is clear. These merely approximate numbers (for Great Britain in the daytime during the summer) differ in different parts of the earth, and it is not uncommon to find alternations of increase and decrease at certain times. (The rate of decrease of temperature in going above sea-level in mountainous regions of this country, is rather less than these values, being about 1° F. for every 300 feet.) Since that time M. Hermite, a French observer, sent up a balloon with recording instruments, which rose to a height even greater than that attained by Messrs Glaisher and Coxwell. It ascended to a point where the pressure was only 4·1 inches of mercury and the temperature −104° F., having probably risen to a height of 10 miles in the air. From the results of this ascent it would seem that the temperature of the air decreases pretty regularly above 12,000 feet at the rate of 1° for every 330 feet rise in the air.

But more recent observations recorded by the self-registering instruments taken up by means of kites (at the Observatory at Blue Hill, near Boston, Mass., U.S.A.) have shown that this decrease does not extend indefinitely upwards, but comes abruptly to an end after a certain altitude is attained. The most remarkable discovery has been made of the existence of an "isothermal layer," whose temperature varies very little over a wide vertical range.

Up to a certain height varying somewhat with the time, pressure distribution, and latitude of the region, the temperature falls to a minimum value. Then the diminution abruptly ceases and for a great height the temperature is almost constant, "showing on the average a slight tendency to increase" (Gold). The average height of this isothermal layer for places in Europe, near latitude 50°, is given at 11 kilometres (about 7 miles), and the temperature as −55° C. (= −67° F.). The annual variation in this height is about 2·5 kilometres, and in temperature 10° C. (1½ miles and 18° F.). On the whole the height is greatest in autumn, and its temperature greatest in summer. The value for Europe is about 10 kilometres (6 miles) over regions of low pressure, and 12·5 kilometres (8 miles) over places of high pressure. Thus the results of Hermite, given above, must have been

CHAPTER XVIII

PRACTICAL APPLICATIONS—"SIGNS" OF RAIN—THE LEECH—SEASONAL CHANGES — MIGRATION OF BIRDS — PLANT "PHENOLOGY" — FLOWERING OF PLANTS—FALL OF LEAVES—SEASONAL PREVALENCE OF DISEASES—SALUBRITY OF PARTICULAR REGIONS—OZONE.

AMONGST miscellaneous phenomena directly dependent on meteorological conditions, the first appearance of birds in the spring, the dates of budding of trees and flowers, the migration of birds and the "falling of the leaf" in autumn, the variation in the times of harvest (corn, vintage, etc.), have been noticed by various observers from comparatively early dates. From the recorded dates of the vintage ("grape harvest") in Central Europe for the last five hundred years, Dr Brückner was enabled to arrive at important inferences as to the succession of warm and cold periods during that time (chap. xv.).

On the amount of rainfall in greater or less quantity throughout the year depends the suitability or otherwise of different districts for various crops. The relation of climate to health is another important branch of applied meteorology, and has always attracted a good deal of attention, though it is only of recent years that the subject has been treated in a careful scientific manner. Statistics dealing with the seasonal variations of epidemic diseases are of interest to the medical practitioner, for it is fairly well known how certain complaints are more prevalent during certain seasons of the year than at other times; for instance, scarlet fever and enteric give the maximum mortality during the *autumn* months, October and November, whilst these effects are at a minimum in the *spring*, March to May (Archibald). The peculiar real or alleged beneficial effects of ozone are also points about which there is a good deal of imagination, but little real knowledge.

Brückner's work on the oscillations in mean temperature and rainfall, has already been mentioned (chap. xv.), as also his attempt to deduce an average period of about thirty-five to forty years for the recurrence of similar weather conditions.

Throughout the literature of almost every nation we meet with numerous proverbs relating to the appearance or disappearance of birds and insects, and the blossoming, fruition, etc., of plants in greater or less abundance has been taken as a sign of the severity or mildness of the coming winter, whilst inferences are also drawn from their earlier or later appearance.

Many signs of coming rain, some real and some imaginary, are collected from the behaviour of animals, birds, and plants. The remarks of

Mr Inwards ("Weather Lore") are so appropriate in this connection that we will now proceed to quote them *verbatim*:—

"The observations of naturalists, shepherds, herdsmen, and others, who have been brought much into contact with animals, have proved most clearly that these creatures are cognisant of approaching changes in the state of the air long before we know of their coming by other signs. To many kinds of animals, birds, and insects the weather is of so much more importance than to us, that it would be wonderful if nature had not provided them with a more keenly prophetic instinct in this respect."

As signs of coming rain, the uneasiness of domestic animals, the low flight and short excursions of birds and insects, the behaviour of bees, etc., are well known (*see* also chap. xiv.).

The leech would appear to be an especially sensitive subject, from whose various behaviour a variety of influences may be drawn. Thus we are told that he is always agitated by changes of weather. He moves about very briskly before high wind. A leech confined in a bottle of water creeps to the top of the bottle, but *soon sinks* previous to slight rain or snow, but if the rain is likely to last longer, he remains a longer time at the surface. Before the approach of thunder he starts about in an agitated and convulsive manner (Inwards). Other inferences from the flight and movement of rooks are known in Scotland (and this country also). Thus their low flight and frequent return to the rookery are signs of coming rain, sitting on dykes and palings in rows are signs of wind, whilst their high flight, on going home to roost, indicates that the next day will be fine. A Devonshire proverb says: "If rooks stay at home, or return in the middle of the day, it will rain; if they go far abroad, it will be fair."

As signs of a seasonal character, the early migration of the summer birds is taken to indicate a cold winter; the appearance of the robin, woodcock, etc., tells the same story, whilst the martin is supposed to presage milder conditions.

Of still more immediate connection with meteorological conditions is the study of plant "Phenology" (from Greek *φαίνω*, more correctly, middle, *φαίνομαι*, I appear), or the study of the conditions governing their flowering, fruition, and abundance, or otherwise. Plants are much more closely influenced by conditions of temperature and moisture than animals. The practical interest of this study, as enabling inferences to be made as to the proper time for planting crops in various situations, the probable yield, etc., matters concerning which at present personal experience of former results is our only guide, is evident. By a careful study of observations of the times of occurrence of the various phenomena it is not too much to hope that in time valuable information, based on the accumulated experience of many, will enable better results to be obtained in the future than has been the case in the past. A division of the spring time into five periods, each characterised by the blossoming of certain plants, has been made by Von Reichenau for the middle Rhine region of Germany.

The first period, when the following plants blossom—daphne, hepatica, pulsatilla.

The second period, for the blooming of the stone fruits—apricots, peaches, cherries, and plums.

The third period, for the seed fruits—pears and apples.

The fourth period, "full spring."

The fifth period, the end of spring, characterised by the flowering of rose, linden, and vine (Waldo).

The oscillations in temperature of different years are well shown by the range in the date of the first appearance of bloom on the various species of plants, there being a range of thirty-nine days in the case of the elm and apricot, but only nineteen days for the vine.

This subject has been rather a favourite one with naturalists, and attempts have been made to draw up a calendar of "Indications of Spring," the times of earliest and latest flowering.

Mr Inwards, in his "Weather Lore," gives a long list (from Hone's "Everyday Book") of common plants, and the times at which they ought to be in full flower, from which we extract the following, in order of date. Beginning with the groundsel, which should appear on January 2, the dead nettle and anemone follow, and by the end of the month the double daisy should be in flower. In February the snowdrop first appears, soon followed by the primrose, hyacinth, and crocus, whilst towards the end of the month the peach is in flower. In March we have first the chickweed, this is followed by the violet in the middle of the month, and the marigold and oxlip at the end. April opens with the white violet, the wood anemone follows, then the dandelion, and later on the harebell, the cowslip coming last. The rhododendron should be in flower at the beginning of May, then the lily of the valley, the poppy, monkshood, and horse chestnut. The lilac follows towards the end of the month, and the buttercup at the end. In June, "the month of roses," we have, of course, the various varieties of the "queen of flowers," also the pimpernel and pink at the beginning, the horned poppy in the middle, the St John's wort, sweet-william, and cornflower towards the end of the month. July opens with the agrimony and the white lily; the nasturtium and snap-dragon follow, the convolvulus and sweet-pea come later, and towards the end of the month the field camomile makes its appearance. The yellow tiger lily opens early in August, with hollyhocks and bluebells; the common balsam appears in the middle of the month, then the sunflower, with the golden rod and yellow hollyhock at the end.

Not many new flowers make their appearance in September; mushrooms are plentiful, springing up after every shower; the autumn crocus and the passion flower are in bloom. In October the soapwort, camomile and chrysanthemum first make their appearance, then later we have the holly, yarrow, and ten-leaved sunflower. In November the laurustinum is given for the 1st, the sweet butterbur for the 25th. For December we have the Barbadoes gooseberry and the *arbor vitæ* in the first few days, whilst the cedar of Lebanon and the purple heath come at Christmas.

A converse phenomenon to flowering, *i.e.*, the fall of the leaf, is subject to considerable local and temporal variation. In some years the trees will begin to drop their leaves early and quickly, whilst the process will last for some weeks in other years. Moreover, the sequence of falling varies; for instance, as indicated by the proverb:—

> "If the oak's before the ash
> Then you'll only get a splash;
> But if the ash precedes the oak
> Then you may expect a soak."

The amount of rainfall thus being supposed indicated by the relative times of fall of the two different kinds of trees. The greater or less abundance of fruit has also been thought by some to have a bearing on the probable character of the coming winter. Thus we are told: "If the oak bears much mast, it foreshows a long and hard winter"; and we have also:—

"Many hips and haws,
Many frosts and snaws."

The abundance of fruit being thus supposed a provision for the birds during a long, hard, and trying winter. The thin or thick skin of the onion is thus apostrophised:—

"Onion's skin very thin,
Mild winter coming in;
Onion's skin thick and tough,
Coming winter cold and rough."

Amongst many other prognostics of severe weather we have such as the following:—"If many white-thorn blossoms or dog roses are seen, expect a severe winter" (Inwards). But this, we are told, is a fallacy. It certainly presupposes a wonderful degree of prescience on the part of the vegetable kingdom! "If in the fall of the leaves in October many wither on the boughs and hang there, it betokens a frosty winter and much snow." And again we learn:—

"If on the trees the leaves still hold
The coming winter will be cold."

As already stated (chap. xv.), by his examination of the records of the times of the "grape harvest" in France, Switzerland, and the Rhine district for several hundred years past, Dr Brückner has been able to confirm his results as to a period of general oscillation of mean temperature of about thirty-four or thirty-five years or so, and from lists of severe winters given by Pilgram and others, he has extended his researches as far back as A.D. 800, a period of over one thousand years.

A comparison of the average quinquennial or "lustral" periods ("of five years"), with the records for rainfall and temperature, shows that "in general" the earlier period of harvest is identical with that of high temperature and small rainfall, whilst conversely the times of late harvest and low temperature occur together (Waldo).

An important branch of applied meteorology, the collection of statistics bearing on the relation of climate to disease, and the greater or less healthfulness of certain localities, has attracted considerable attention at different times, and though much remains to be known, some conclusions of great interest have been arrived at. It has long been known that certain epidemics are more prevalent at one season of the year than another, and we have already referred to the fact that whilst enteric fever is most prevalent and fatal during the autumn, on the other hand smallpox is less prevalent at that time, but most fatal later in the winter. Influenza, heard much more of in recent years than formerly, "is evidently propagated through the air." The air of cities usually contains far more dust particles than that of the country, and is less healthful than the latter (with exceptions), for in certain districts remote from towns decaying vegetable growths may also occasion malarial fevers, as is the case with some regions of Italy, to say nothing of tropical districts, "mangrove swamps," etc. The difference between extreme summer and winter temperatures is a far more important factor affecting the health of the inhabitants of a district than the mean annual value of the temperature. Thus the mean annual temperature of New York is not far from that of London, but it is well known that the heat of summer is much greater, and the cold of winter more severe, in the former than the latter, the differences being those characteristic of "continental" and "insular" climates respectively.

The smaller the annual range of temperature, other things being equal, the more salubrious the climate, and in general the proximity of the sea is most effective in equalising thermal conditions.

There are a number of factors sometimes enumerated as affecting the climate of any district:—*Firstly,* the latitude; the nearer the Equator, the hotter the climate. *Secondly,* situation in Northern or Southern Hemisphere.

Places in the Southern Hemisphere, owing to the great preponderance of water, are subject to much smaller variations of temperature than those of the *same latitude* in the opposite hemisphere. *Thirdly*, easterly districts on either continent (*e.g.*, the Eastern United States and China) are subject to greater variations of temperature than westerly ones (*e.g.*, California, France).

Amongst *other* causes, elevation or altitude above sea-level is very important. The inland plateau of Tibet, notwithstanding its low latitude, is subject to very severe weather in winter. The neighbourhood of mountain ranges, situation with respect to winds, the influence of hot or cold currents, etc., all exercise important influences, many of which have been dealt with in the course of this work.

The greater or less amount of ozone and its real or imaginary influence upon the healthiness of a district are matters upon which much speculation has been indulged in, but very little is really known. Ozone appears to be formed during thunderstorms by the passage of the electric spark through the air, and is artificially produced by passing a series of discharges through oxygen, its name (from the Greek ὄζω, I smell) being given to it from the peculiar smell often noticed during the working of electrical machines. Chemically, it appears to be compressed oxygen, the active element in the air. If a quantity of oxygen be submitted to the silent discharge, it will be found to contract in volume, but on being heated to about 500° F. it recovers its original bulk (allowing for the increase of volume due to the elevated temperature). Chemically, ozone is regarded as oxygen in which three molecules occupy the space of two in *common* oxygen, and the third molecule is held loosely in combination with the other two, so that it is readily given off, and oxidises combustible matter, destroying decomposing animal and vegetable substances by uniting with them, thus acting as a purifying agent. It appears to be more abundant near the sea coast than in inland districts, and is found in greater abundance in spring than at other times of the year. A smaller amount is found in summer, less still in autumn, and least of all in winter.

Other observations, however, seem to show that the amount of ozone in air unexposed to the influence of the land is very nearly constant (Thorpe). The air just over marshes or malarial districts contains little or no ozone, but in the heights above such places some may often be found. No ozone can be detected in cities or in the air of dwelling-rooms. Though obtained as we have stated above, no method has yet been devised whereby it can be isolated; it is always found mixed with a much larger quantity of common air or oxygen, and even when most concentrated does not form more than about 8 per cent. of the mixture.

Paper moistened with a solution of iodide of potassium and starch, and exposed to ozonised air, is rapidly turned a brilliant blue colour; this is one of the most delicate tests for its detection, but is not an infallible one, since other substances besides ozone affect the starch in the same way. Whilst a small quantity may be beneficial, on the other hand, however, there is little doubt that an excessive amount of ozone in the air is injurious to health.

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PRINTED AT THE EDINBURGH PRESS, 9 AND 11 YOUNG STREET.