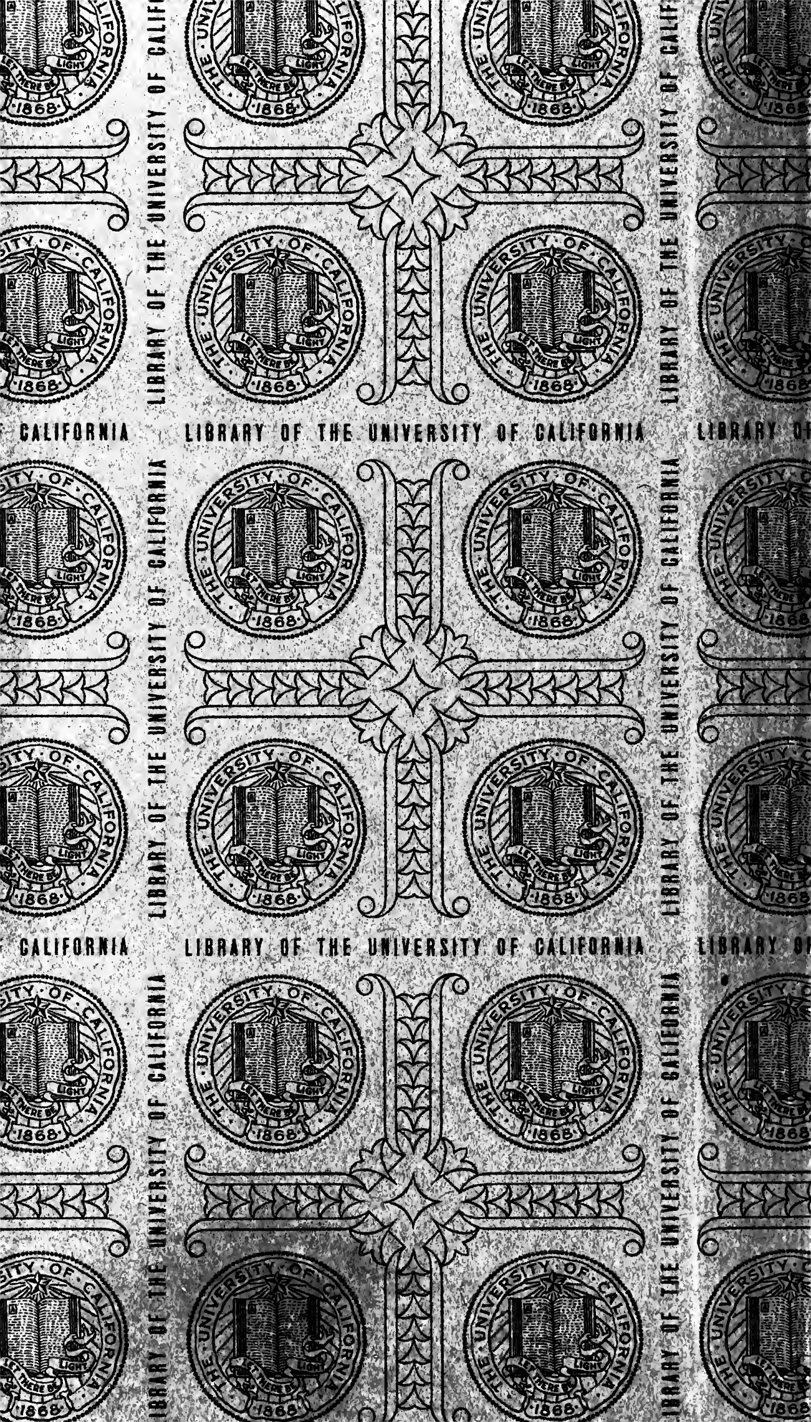


PHYSICAL GEOGRAPHY,

OR

THE TERRAQUEOUS GLOBE

AND

ITS PHENOMENA.

G H Ford.

THE END OF A GLACIER WITH BLUE BANDS.

PHYSICAL GEOGRAPHY,

OR

THE TERRAQUEOUS GLOBE

AND

ITS PHENOMENA.

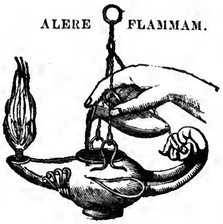
ILLUSTRATED WITH
125 WOOD-ENGRAVINGS, FRONTISPIECE, AND 12 MAPS.

BY

WILLIAM DESBOROUGH COOLEY.

LONDON:
DULAU AND CO., 37 SOHO SQUARE.
1876.

PRINTED BY TAYLOR AND FRANCIS,
RED LION COURT, FLEET STREET.



PREFACE.

MANY, perhaps, on looking at this volume will be disposed to ask, "What is Physical Geography?" To this question (which, under existing circumstances, is not inexcusable) I would reply that it is the department of science which embraces the course of Physics reigning on the earth's surface, over land, sea, and air, and of which, as it depends to some extent on the feature of that surface, Geography is a function.

Physics (from the Greek φύσις, nature), or the various branches of the science of nature ordinarily combined under the name of Natural Philosophy, have for subject not inert matter merely as such, but the properties, motions, and other incidents of bodies, their mutual relations, their causes and effects. Nature is regarded by the philosopher as an organic whole, connected throughout and regulated by laws. In his language the word Physical always refers to nature thus conceived, to its rational principles and its laws. Thus, while Descriptive Astronomy depicts the heavens and enumerates the various bodies that revolve in them, Physical Astronomy explains how they are governed in all their movements by gravitation.

Immanuel Kant, the great philosopher who first drew attention to Physical Geography, was disposed to allow it a very wide range. In discussing it he roved through all nature. Dr. J. C. E. Schmidt, whose work on the subject is in the mathematical treatment most complete, and Dr. Maedler, the Astronomer, have both viewed Physical Geography as a part of the Philosophy of the universe; and it occupies no small part of A. von Humboldt's 'Kosmos.'

Sir J. Herschel describes it in the following words:—"We find ourselves thus introduced to the domain of Physical Geography, or the description of the actual state of the earth's surface in its three great divisions—land, sea, and air, as prepared for the habitation of organic beings, and as exhibiting the play of all those complex agencies on which depend the distribution of temperature and moisture, aerial and oceanic currents, and those conditions which, under the general title of climate, determine the abundance and limits of vegetable and animal forms." Thus as to the objects and scope of Physical Geography we are fully instructed by the eminent men who brought it into vogue.

But about half a century ago, when physical science was little cultivated in England, some ardent students of Geology were pleased to collect those rudiments of Geography which are more immediately connected with their own pursuits, and converting them into superficial treatises of Geology, presented them to the public ennobled with the title of Physical Geography, the word physical being here used in its vulgar sense, to exclude moral, political, and other such considerations. In this sense it is evident that every book on Geography includes Physical Geography.

In the writings of Sir Charles Lyell and of Sir R. I. Murchison, the expression Physical Geography always signifies merely the conformation of the earth's surface. Mr. B. Jukes defended this as the correct application of the name. When these authors tell us of frequent changes in the physical geography of the earth, we must understand them to speak of an altered conformation or change in the distribution of sea and land. It is obvious that in this sense Physical Geography cannot be a science; yet it is often appealed to as such. The same confusion of ideas has descended to the disciples of the above-named founders of Geology; and we have at present numerous treatises on Physical Geography which are in reality merely outlines of Geology, without a trace of Physical Science.

Under the patronage of the Royal Geographical Society, the study of Geography has been divided into two branches, viz. Physical and Political; but the purpose or advantage of this division has never been explained. Indeed it would appear, from the published specimens of the examination papers, that no thought has been expended on the subject. Synclinal and anticlinal lines, escarpments, and all details pertaining to Geology belong to Physical Geography; but mountains, rivers, and every thing else lie equally within the province of Political Geography. In short, a feeble and useless attempt is made to distinguish between a description of the Earth and a description of the countries and kingdoms of the Earth, the natural philosophy involved with geographical considerations being in the mean time forgotten.

Some writers have included in Physical Geography the distribution of plants and animals over the earth. There is, however, a broad distinction between Physical Science and Natural History, and the attempt to blend them can never succeed; for Natural History is made up of multitudinous details. Species of plants and animals are reckoned by thousands. But the generalizations of science ought to follow the particulars, and can be fully understood only by those well acquainted with the latter. An attempt to explain the geographical distribution of plants, for example, if it does not give a full account of them, but only their names, must be dry and uninstructive; but if it does give such an account, it is no longer Geography, but Natural History.

Since the first sheet of this volume was sent to press, the number of asteroids discovered has been increased by 8. They now amount to 176.

W. D. C.

November 26th, 1875.

CONTENTS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER VIII.

CHAPTER IX.

CHAPTER X.

CHAPTER XI.

CHAPTER XII.

CHAPTER XIII.

CHAPTER XIV.

CHAPTER XV.

CHAPTER XVI.

CHAPTER XVII.

CHAPTER XVIII.

CHAPTER XIX.

CHAPTER XX.

CHAPTER XXI.

CHAPTER XXII.

CHAPTER XXIII.

CHAPTER XXIV.

CHAPTER XXV.

CHAPTER XXVI.

CHAPTER XXVII.

CHAPTER XXVIII.

CHAPTER XXIX.

CHAPTER XXX.

PHYSICAL GEOGRAPHY.

CHAPTER I.

Universal Character of Terrestrial Physics.—The Sky.—Apparent Motion of the Heavens.—The Planets.—The Sun controls the System.—Universal Gravitation.—The Cosmogony of the Ancients.—Measure of Gravitation.—Estimation of Distance in the Heavens.—Parallax.—Amount of the Lunar Parallax.—The Sun's Parallax—how found from the Transit of an Inferior Planet.—The Solar System—its magnitude.—Superior and Inferior Planets.—Asteroids.—Comets.—Aspects of Sun and Moon.—Fixed Stars—their classes and numbers.—Binary and Multiple Stars.—Nebulæ.—Parallax of the Stars.—The Nebular Hypothesis of Creation.—Opinions of Kant, Herschel, and Laplace—Objections.

Since Physical Geography has for its object to establish the connexion of Physics with Geography, or to explain how physical laws and phenomena are modified by position on the earth's surface, we cannot commence the study of it more fitly than by making ourselves acquainted with the chief physical laws of the universe and with the system visibly upheld and controlled by them. The science of nature compels us to carry our views beyond the earth. It is from observation of the heavens that we can best learn the nature of gravitation. For the cause of the alternation of night and day, and of the change of seasons, we must look to the earth rotating on its axis, while revolving at the same time in its orbit round the sun. As to the primæval condition of the earth when first called into existence, no attempt can be made to investigate it without considering at the same time the origin of the system of which the earth is a member.

The sky appears by day to be an azure vault*. Its colour,

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* The word "skye" in Danish signifies "a cloud," and may possibly be connected in origin with the Greek *σκιὰ* (a shade).

Ox

however, is not due to the distant heavens, but to the terrestrial atmosphere, which, by absorbing a certain portion of the light, colours that which it transmits. Consequently when viewed from a considerable elevation, where the air is much rarefied, the sky appears almost black. As soon as the more dense atmosphere, retentive of illumination, is left behind, the eye discovers a dark unfathomable abyss, which, being penetrated by it equally in all directions, seems to have the form of a vault or concave sphere.

The splendour of the sun above the horizon extinguishes all other objects in the visible heavens. But after sunset, and when twilight is at an end, the sky resumes its natural darkness, with innumerable stars, minute fountains of light, irregularly scattered over it. These are to ordinary perception immovable with respect to each other, and keep the same relative positions from age to age. The whole spangled canopy moves with perfect constancy from east to west, or from the left to the right hand of one looking southwards (in the northern hemisphere), and makes the circuit of the heavens in the sidereal day, which is the true or perfectly constant unit of time, being equal to 23 hours 56 minutes, and 4·09 seconds of mean solar time. The sun, participating in the general diurnal movement of the heavens from east to west, moves also from west to east among the stars at the mean rate of 59 minutes, 8 seconds of space, or nearly twice its own diameter, in a day, so as to complete the circuit of the heavens in the tropical year, or 365 days 6 hours 9 minutes and 9·6 seconds. The apparent diurnal revolution of the collective heavens is obviously due to the earth's rotation on its axis, the real motion of the spectator causing the apparent motion of the scene before his eyes. The sun's apparent course among the stars is, in like manner, the effect of the earth's advance in its orbit. The earth, while rotating on its axis, also goes forward in its path; and the sun therefore seems to go in the opposite direction. When the earth's diurnal rotation is complete with respect to the stars, it must still continue for 3 minutes 56 seconds in order to come up with the sun and complete the mean solar day of 24 hours.

In the zone of the heavens immediately about the ecliptic or sun's path, and which is called the Zodiac, from *ζώδιον*, a figure of an animal, because the stars within it were, for convenient reference, anciently grouped into such imaginary figures, may be seen a few small bodies, hardly distinguishable by the naked eye from stars, though differing from them in having measurable disks as well as motions generally direct or from west to east, yet also, in some instances and at certain periods, from east to west, or retrograde. Some of them make in the course of years, by what appears to be a very complicated path, the circuit of the heavens. Others never extend their excursions beyond a limited distance from the sun. These bodies are called Planets, or wanderers; and close observation discovers that they all revolve round the sun, nearly in the same plane, which is called the plane of the ecliptic, because in it alone take place the eclipses of the sun and moon; that the earth is one of the same class, being itself a planet; and that the apparent complexity of the planetary motions is due to the circumstance that the proper motion of the earth round the sun is combined with those of the planets. If the earth, E (fig. 1), stood still while the planet P described its orbit round the sun, from *a* to *b* and back again, the path of P would be a straight line back and forward, supposing P's orbit and that of the earth to be in the same plane—or a compressed ellipse, if the orbits be inclined to each other at a small angle. But if the earth, instead of standing still, constantly moves on in its orbit, the line marking P's course will continually change its position; the alternate movements of the planet back and forward will appear unequal, and the ellipse described by it will assume a new and convoluted form (fig. 2).

Fig. 1.

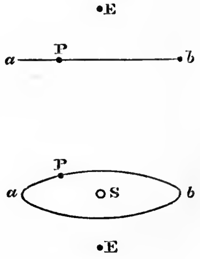
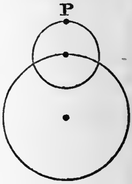


Fig. 2.

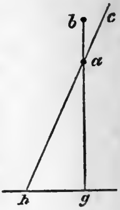
The sun, by far the largest body in the solar system, occupies the centre, and holds all the planets in their orbits by its attraction; for it can be perfectly demonstrated that the rectilineal course in which they would hurry along if left to themselves is converted by the central attraction into an elliptical orbit round the central body. The attraction exercised by the sun in consequence of its surpassing magnitude, presents to the earth the most striking example of universal gravitation. The ancients did not regard the sun as the central body. They believed the earth to be the fixed centre round which the sun and all the bodies in the heavens moved in circles; for they deemed the circle the most perfect figure. When movements decidedly not circular were subsequently detected in the heavens, they were referred to epicycles, or circles the centres of which revolve on other circles (fig. 3). It is evident that by this contrivance, with careful adaptation of the circle and its epicycle in respect of size and velocity of revolution, an ellipse or any other curve may be approximately represented.

Fig. 3.



The attraction of gravitation is manifest in its action; but to calculate its force it is necessary to know the distance between the attracting body and that attracted. Observation of the heavens generally reveals only proportional or relative, but no absolute, distances. Thus the distance of the sun from the earth is easily found to be about 400 times that of the moon; but the absolute and exact distances of those bodies are not so discoverable. The distance of an unapproachable object can be found only by observation of its parallax, or that change in its apparent place which is caused by and corresponds with the spectator's change of place, the distance between his successive positions being known. The optical coincidence of one object (*a*, fig. 4) with another more distant, *b*, takes place only when the observer stands in the continuation of the line *ab*, which joins them both. When he moves away from that line, or from *g* to *h*, the nearer object moves, in respect of the more distant, in the opposite direction, to *c*; and the nearer it is to the observer, the greater will be its angular motion. If the more distant object be a fixed star, then lines drawn from the observer to the star, whatever be his change of place, may be considered as parallel to each other, because, the earth being a mere point as seen from the star, any angle subtended by a portion of its surface must be wholly in-

Fig. 4.



appreciable. This being understood, let us suppose that at two observatories (*a* and *b*, fig. 5) widely asunder and, to make the case more simple, on the same meridian, the moon's position be noted at one and the same instant, the effect of the distance between the observers will be evident in the circumstance that the moon will appear at the northern station to be further south, at the southern further north, among the stars. The difference between these two observations, or the angle *a* M *b*, is the parallax corresponding to the measured arc between the two observatories; and from this again may be accurately deduced the angle P M C (fig. 6), the horizontal or maximum parallax (for 90°). This, called also the geocentric parallax, is that which would be found by observations made at the pole and the centre of the earth (were such observation possible), and is the recorded lunar parallax of astronomers.

Fig. 5.

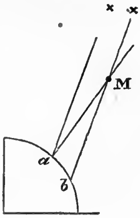
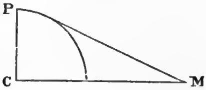


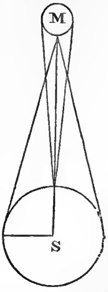
Fig. 6.



The horizontal parallax of the moon, or the angle subtended by the earth's semidiameter as seen from the moon (fig. 7), is found to be 57′ 2″·325. Consequently, as the sine (0·165779) of that angle is to radius (1), so is 3912, the earth's polar semidiameter, to the moon's distance, or 238,793 miles, about 60 times that semidiameter. Again, it is obvious that when bodies are compared together at a fixed distance, their real and their apparent magnitudes are in the same proportion. Now the earth seen from the moon (E, fig. 8) has a diameter of 114′ (double of the horizontal parallax), while that of the moon seen from the earth is but 31′·7. It follows, therefore, that the moon is to the earth in diameter as 31·7 to 114, in volume as 1 to 49.

Fig. 7.

Fig. 8.

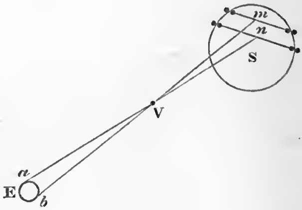


The sun's parallax, owing to the distance of the luminary, is so small an angle that it is hard to determine it with the precision required by its importance; for the smaller the angle the greater proportion do the inevitable errors of observation bear to the whole result. Were it possible to find exactly the instant of lunar quadrature, or half-moon, the sun's distance could be exactly derived from it for at that moment the lines S M and E M (fig. 9), drawn from the sun and the earth to the moon, form a right angle, S M E. The angular distance of the sun from the moon, S E M, may be learned from the clock. The three angles of the triangle being thus known, the mutual proportions of its sides are also known; and therefore from the moon's distance, M E, already found, may be deduced the sun's distance. But in this mode of proceeding the fundamental observation can never be satisfactory.

Fig. 9.

A far better means of finding the parallax and distance of the sun is afforded by the transit of one of the inferior planets over the sun's disk. That of Venus, as being nearer to the earth, offers most advantage. Suppose the transit to be observed from two points on the same meridian, then the two tracks seen of the planet's passage over the face of the luminary (fig. 10) will be at some distance asunder and of different lengths. At each place of observation the contacts, internal and external, of the planet with the sun's edge must be carefully noted at ingress and egress. This noting of time may be done with extreme precision, as the transit is comparatively slow. The length of each track is proportional to the time taken to perform it, which is easily observed. The size of the solar disk being well known, there can be no difficulty in placing the two observed chords accurately within it, and thus ascertaining the distance, $m\,n$, between them. But as the distance of Venus from the sun, V S, is to its distance from the earth, V E, so is the distance, mn, between the observed chords to the

Fig. 10.



true solar parallax, which is thus found. The differing observations of transit made at different places, and not on the same meridian, are all conducive to accurate results, though by means of intricate calculations. But here it is enough to point out the general principle and method of proceeding.

Astronomers have been long agreed in adopting 8″·6, or more strictly 8″·5766, as the best expression of the sun's parallax; but observations with improved instruments, together with theoretical considerations of great weight, recommend the adoption of 8″·89 as a better estimate. This makes the sun's distance from the earth to be about 91,600,000 miles. This increase of the solar parallax, it may be observed, is less than the hundred-and-eightieth part of a minute of space, or of the smallest point clearly visible to the naked eye; yet it has the effect of reducing by one twenty-eighth part the scale of the whole solar system, bringing the earth nearly four millions of miles and the polar planet Neptune 100 millions of miles nearer to the sun *. Having determined the distance of the central body and observed the movements of the planets about it, or the periodic times and variations of speed with which the orbits are described, we thence deduce their real dimensions; while the measurable disks of the planets, varying in size as they are more or less distant, afford additional means of arriving by repeated observation at accurate results.

The bodies composing the solar system, with their relative magnitude, distances from the centre, and densities, the unit of measure under each head being furnished by the earth, are as follows:—

	Diameter.	Distance.	Density.
The Sun	107		0·25
Mercury	0·395	0·387	1·12
Venus	0·984	0·7233	0·92
The Earth	1	1	1
Mars	0·529	1·523	0·95
The Asteroids			
Jupiter...............	11	5·202	0·24
Saturn...............	10	9·538	0·14
Uranus	4·35	19·182	0·24
Neptune	5·23	30·036	0·14

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* A minute of space is about the smallest point plainly discernible by the human eye.

The equatorial diameter of the earth is 7924 statute miles; that of the sun, therefore, being 107 times as much, will be 847,868 miles. The distance of the earth from the sun, the unit of distance of the preceding Table, is about 91,600,000 miles; the distance of Neptune therefore from the centre of heat, light, and gravitation is 2750 millions of miles. The density of the earth seems to be about 5·53, that of water being taken as unit; and the mean density of the minerals on its surface being not more than 2·66, it follows that its density must increase downwards till at the centre it is more than double of that at the surface. The density of Saturn, 0·14, being considerably less than that of water (0·181 when the density of the earth is taken as unit), that planet would appear to be no heavier than cork.

The earth, the largest of the first four or inferior planets, is also distinguished from them by having a satellite. Jupiter, the largest of all the planets, its bulk being 1330 times that of the earth, has four satellites. To eight satellites, which are most of them discoverable only by very powerful telescopes, Saturn adds a peculiar appendage in the form of a flat hoop ring, or two or more rings lying close together. The satellites of Uranus, six in number, were discovered by Sir Wm. Herschel; but as two of them have never been rediscovered by succeeding astronomers, their existence is now matter of doubt. These satellites present a remarkable singularity, their orbits being nearly perpendicular to the plane of the ecliptic, while their motion in these orbits is said to be retrograde. The great distance of Neptune secures his attendants from observation, and as yet the existence of only two satellites has been perfectly ascertained.

Mercury and Venus coming between the sun and earth, and confined in their excursions to a limited distance from the former, are called inferior planets, while the other five, beyond the earth or further than it from the sun, are styled superior planets. A more real distinction, however, appears to exist between the two groups, of four each, between which revolve the small planets or Asteroids. Among the characters which separate them may be mentioned their very different specific densities, the four planets next the sun having collectively a density five times that of the superior group or four remoter planets.

The attempts made to find empirical rules which might reduce to order the distances between the planets, led to the conjecture that between Mars and Jupiter there remained unoccupied the space for a planet.

This speculation obtaining vogue, the discovery of a planet in the vacant space was long eagerly looked for. At length, on the first night of 1800, the last year of the 18th century, expectation was gratified by the discovery of Ceres; and in the seven following years three more small planets, Juno, Pallas, and Vesta, were found in the same zone of the heavens. But these minute bodies did not quite meet the views of those who looked for a single planet and a suitable neighbour for Mars and Jupiter; and as they seemed to be in some degree connected together by contiguity of orbits and community of nodes, the opinion gained ground that they are but fragments of the missing planet. Thirty-eight years, however, elapsed without any addition to their number. At length the general improvement of telescopes and the better acquaintance with the small stars about the ecliptic, rendered easy by elaborate catalogues, have enabled astronomers, within the last thirty years, to pick up 144 more of these supposed fragments; so that the Asteroids, as these small bodies are generally called, all describing elliptic orbits round the sun, now amount to 148. Most of these are telescopic objects not larger perhaps than Sicily or Ceylon would be if rolled up and translated to the heavens. Their orbits are singularly interwoven, many pairs of them seem to have started from the same nodal point. Among their singularities may be mentioned irregularity of figure, for many of them are not spheroidal; and also the great development of the atmospheres, very ample and apparently dense, that enwrap these scarcely visible wanderers in the heavens.

The sun has, besides the planets, another retinue of a different character. A comet is easily distinguished by its coma or hair-like appendage, and by the brush of light, generally called a tail, which follows it to the perihelion or point of its orbit nearest to the sun and thenceforward precedes it. Comets, like planets, revolve round and owe their light entirely to the sun. But while planetary orbits differ but little from circles, those of comets are extremely eccentric; so that the comet, which is visible for a few days as it approaches the sun, darts off again to the distance perhaps of Saturn, and remains out of sight for some years. To the orbits of many of the comets no limits can be assigned; and even when the orbit is known and calculated, it is liable to be so changed by disturbance as to be no longer recognizable. The planets revolve all nearly in the same plane and in one direction, whereas comets, both direct and retrograde, are confined to no plane, though they seem to be crowded about the planes inclined at an angle of 45° to the plane of the ecliptic. Comets appear to have very little density. They might therefore be supposed to be formed of gas, if it were possible to understand how gas could be confined to definite figure and volume without compression.

The comets are probably much more numerous than the planets; but they are still and perhaps will ever remain very imperfectly known, since, owing to their proximity to the sun when visiting the planetary system, their passage of the visible heavens is chiefly or even generally performed in the day time. Those whose orbits and periods are ascertained are about 300, and are distinguishable into two classes, viz. one of short period (3 to 7 years) and one of long period, or about 75 years. But some seem to have periods of hundreds or even thousands of years.

Halley's comet (1682), the first whose return was predicted, may be retraced with much probability through 2000 years, to the birth of Mithridates. Encke's comet (1786) seems to draw closer to the sun at every return, as if destined to merge in the central body. Biela's comet burst in two during its appearance in 1826; and its fragments still continued their courses as separate bodies at no great distance asunder.

Viewed with a good telescope the sun presents a surface resembling a slightly agitated sea in which the crests of the waves are peculiarly brilliant, while the whole is dotted over with black points like pores. According to recent observations the luminous ridges have the shape of willow leaves crossing each other in all directions, the angular interstices between them where they cross being the pores. The brilliant surface is often rent at a little distance from the equatorial region so as to disclose what seem to be piles of clouds, growing darker downwards till they terminate in a black chasm. From this it might be supposed that the body of the sun lies wrapt in total darkness, beneath a dense and externally luminous atmosphere. But if it be considered that the shadows of clustered trees at a little distance on a summer's day seem quite black, though in reality there is broad daylight within them, it will be manifest that the strong contrast between the sun's surface and the deep recesses of its spots, does not prove the absolute darkness of the latter.

The moon, though of no importance in comparison with the sun, is hardly a less-interesting object. It is obviously much the nearer of the two, so near indeed that, aided by its changing phases, we can plainly perceive its globularity. We learn from it the wide difference between a self-luminous body and one that shines only with reflected light; for the light of the full moon, which is nearly as large as the sun, is at the utmost but $\frac{1}{300000}$ of the sun's light. In the telescope the moon presents a remarkable scene of aridity and desolation, being covered with bare rocks which have never been worn by rain or humidity, and with plains deeply cracked in all directions, and in some places calcined as it would seem to whiteness. But the chief peculiarity of its aspect lies in the multitude of circular hollows with raised edges, commonly called craters, but which look more like traces of the bubbles of a viscous fluid in a state of ebullition.

The stars visible to the naked eye may, to careless glances, seem innumerable. But in truth all the stars visible in Northern Europe, from the North Pole to 36° south latitude, an extent embracing four fifths of the heavens, were found by Argelander to be but 3256. Adding 844 for the invisible fifth of the celestial sphere, he makes the whole number 4100, and supposes that under favourable circumstances very sharp eyes may see 8000 stars. But certainly, in the troubled and vaporous atmosphere of the British Isles, it is very rarely that the best eyes can reckon 2000 stars.

By astronomers the stars are divided into classes called magnitudes, the first six of which are reputed visible to the naked eye. But it is said that in the clear atmosphere of Persia or Eastern Asia, or even in Egypt, the natives can often see those of the seventh and even eighth class. The proportions of the classes are thus shown in modern catalogues of the stars :—

Magnitude.	
1st	11
2nd	33
3rd	98
4th	245
5th	761
6th	3085

This method of classification appears arbitrary, as hardly any two stars are of exactly the same size, and the line separating the classes must always remain indefinite; yet so finely does the eye discriminate in comparing small objects, that confusion and discord proceeding from these estimates of magnitude are much less frequent than might be expected. All beyond the sixth class being ordinarily invisible to the naked eye, are called telescopic stars. As a general (but certainly not a correct) rule each succeeding class contains about three times as many as that preceding it; and as with powerful telescopes this classification is continued to the fifteenth magnitude and even far beyond it, the telescopic stars probably exceed fifty millions. Those entered in catalogues with their places in the heavens determined by observation, now amount to more than 300,000, of which number 66,000 at least are about the ecliptic.

Stars are mere points of light and have no appreciable magnitude whatever. They differ, however, in brightness; and this brightness being attended with irradiation, the image is magnified in the eye; but the telescope strips off the fringe of irradiation and reduces all stars to the common level of points immeasurably small; yet it does not abate the intense light by which some of these points are distinguished from the rest.

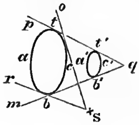
It is not merely in brightness or presumed magnitude that stars differ among themselves. They exhibit also different colours. Some are red or of a deep ruby colour, some yellow or green, and many, generally very small stars, are blue. Clusters are to be seen displaying the richest variety of colour. Again, there are variable stars, which periodically change their apparent magnitudes. The star called Mira Ceti, in the Whale, has a period of eleven months. It appears for a fortnight as a bright star of the second magnitude, then diminishes till it becomes invisible to the naked eye, remains absent for five months, and then reappearing, gradually resumes its original lustre. Algol, a conspicuous star of the second magnitude in Perseus, sinks rapidly to the fourth magnitude, in which state it remains about a quarter of an hour and then recovers, the regular period of this change being nearly 69 hours. A star in Argo (η Argûs) in the Southern hemisphere appears to vary irregularly, and though ordinarily of the fourth magnitude, has at times rivalled the lustre of the brightest stars in the heavens.

Among the most important astronomical discoveries of modern times, is that (due to Sir W. Herschel) of Binary or Multiple stars, forming systems in which one or more stars revolve about another in elliptic orbits and strictly in obedience to the laws of gravitation. Several of these orbits have been already calculated; and looking at one of these double stars, single to the naked eye, but separable by powerful telescopes into two or more, we can in many cases conclude with certainty from the motions of the associated suns, that the real distance between them is not less than the distance from our sun to Neptune, the remotest of the planets. These distant suns may possibly be all surrounded by planetary systems invisible to us, yet causing by their interposition the periodically varying lustre perceptible in some stars.

To the world of stars belong the nebulæ or cloud-like spots of light, many of which have been resolved by the increasing power of telescopes into minute stars, or what is called star-dust. Many, however, remain still unresolved; and it cannot be absolutely asserted that they are composed of distinct stars, though the results of recent researches generally point to that conclusion. The nebula best known to us is the Galaxy or Milky Way, an immense stratum of stars, to which belongs our sun and perhaps all the stars distinctly visible to us in the heavens. Being placed near its centre, we can easily see across it and distinguish the stars composing it; but in the direction of stratification the multitudes of very distant stars gather into what seems to the eye merely a faintly luminous cloud, which forms an irregular belt round the heavens, though many parts of the Galaxy still defy the resolving power of telescopes and retain the character of formless matter. Yet as every improvement in telescopes has been hitherto invariably followed by an advance into the regions of nebulous light, and the reduction of a certain portion of it to stars, it is hardly possible to refrain from concluding that it is wholly composed of stars. The nebulæ assume various forms, circular, elliptical, or of a diffuse, gyrating mass, all representing according to a theory not yet quite extinct, the various stages in the growth of stars from shapeless etherial vapour to a solid sphere. The number of those now known, most of them telescopic, exceeds 3000. They are most numerous in the part of the heavens most remote from the Galaxy.

It has been seen that by ascertaining the parallax of the moon, we also learn its distance; and by similar means we can find the sun's parallax and thereby its distance—a very important step in astronomy. These angles are respectively equal to those subtended at the moon and sun by the earth's semidiameter; but at the distance of the stars the earth is doubtless utterly invisible. No change of place on the earth makes the slightest change in the positions of the stars, and their horizontal parallax therefore is not a perceptible magnitude. But the earth moves round the sun in an orbit the semidiameter of which is 91 millions of miles, or 3500 times the earth's radius. May not this space be appreciable at the stars, and so enable us to detect some change in their position consequent on the earth's revolution in its orbit? The process which aims at determining the heliacal parallax of the stars or the angle subtended at them by the semidiameter of the earth's orbit, has of late years proved successful, chiefly owing to the great improvement of telescopes. In the principal focus of the telescope may be placed a micrometer to measure minute distances, and also a fine and movable thread, gossamer or gold wire, to mark direction. Now many stars are single to the naked eye which are found in powerful telescopes to be double or triple. When such clustered stars lie very close together, it may be assumed that though in the same line of vision, they are in reality wide apart and at very different distances from the earth, consequently they will differ in parallax. Now let two stars thus closely adjacent be constantly observed; if they have parallax they will describe in the course of the year, or while

Fig. 11.



the earth goes through her orbit, minute ellipses (fig. 11), projections of that orbit and differing in size. In consequence of this difference they will change position in respect of each other both in distance and direction; for it is evident that they will be closer together when at *c* and *c'* than when at *a* and *a'*, and also that the lines *mq* and *pq*, which connect them at opposite seasons, will differ much in direction. Comparison with a small star *s* in their neighbourhod, with no parallax, will help to reveal their motions. From these changes may be deduced the figures described by them, and consequently their parallax. In this way have been discovered sidereal parallaxes not exceeding small fractions of a second.

It is calculated that the distance of a star having an annual parallax of one second, must be at a distance, in round numbers, of nearly twenty billions (20,000,000,000,000) of miles—a distance not to be traversed by light (which flies from the sun to the earth in about 16 minutes) in less than 3¼ years. A second of space is about the 60th part of the smallest point distinctly visible to the naked eye; it is the angle subtended by an inch at the distance of 3¼ miles. The parallax of one second was taken as the unit of stellar distance by Sir William Herschel, who supposed that Sirius, the brightest of the stars, was also the nearest. But Sirius has been found to have a parallax of only $0''\cdot230$, and must therefore be removed to the distance of four such units. The nearest star as yet known is *α* Centauri in the Southern hemisphere, the parallax of which, $0''\cdot91$, falls little short of a second. From these examples and from others that might be added, it appears that the apparent magnitude of stars does not depend entirely on their distance, but that they really differ in size and splendour. The light of Sirius is 146 times that of our sun, which at the distance of the former would appear a very small star. According to M. Struve, the average parallax of stars of the first magnitude is $0''\cdot209$, or about the fifth of a second, and their distance such as cannot be travelled over by light in less than 15·5 years. Subsequent observations have shown that these limits are not strictly observed, though probably few stars transgress them. From the furthest stars visible to the naked eye, light cannot reach us in less than 138 years, nor from the most distant stars seen in Herschel's 20-foot telescope in less than 3541 years.

The nature of the starry heavens with their countless worlds, and the origin of the planetary systems of which they probably consist, may be thought to be beyond the reach of human inquiry; but when it is considered how inscrutable appears at first sight the problem of the solar system and how completely it has been solved, it will not be thought unbecoming to listen with deference to those great men who have most effectually aided in the great work, while they state their views of the subject which was ever in their thoughts. And besides, as the origin of the earth, our proper subject, is involved in that of the solar system, we should not be justified in disregarding the speculations of those most competent to treat that difficult question.

It was Sir William Herschel who first suggested that the growth of sidereal bodies by the aggregation of nebulous matter is constantly going forward. He called attention to the fact, already pointed out by Immanuel Kant, that the stars seem all to lie in strata—those visible to the naked eye belonging to the Galaxy or Milky Way, which is a stratum of stars of little thickness, but immense length and breadth. He maintained that nebulæ may be seen in the heavens in all stages of growth and maturity, from the first shapeless gathering of etherial matter to the compact cluster of hardly distinguishable stars. But of late years so many nebulæ formerly deemed unresolvable have been converted into clusters of stars by powerful telescopes, that faith in crude nebulous matter is now much shaken. Yet Herschel's opinion is entitled to great weight. At the outset he believed nebulæ to be composed of minute stars; but persevering study of the heavens for many years, during which he discovered 2500 nebulæ, confirmed in him the belief that unresolvable nebulous matter, the material of stars, still exists in the heavens.

The great German philosopher above named, Immanuel Kant, had already remarked that the planetary bodies of the solar system, all rotating and revolving in the same direction, seem to have been created together, and to owe their motions to a single impulse. With these suggestions as to the materials of creation and the original unity of its movements, it only remained for the profound analyst Laplace to trace from physical laws the mode of operation. He perceived that a mass of gaseous or fluid matter, if made to rotate rapidly, would spread out in the plane of rotation and become a thin disk, growing thinner and wider as the velocity of its rotation increased, till at length, centrifugal force getting the better of cohesion, whole rings or fragments of the edge would fly off, and contracting by cohesive attraction into spheroidal masses, would continue to revolve round the centre from which they broke away. But in these liberated masses the velocity of the outer edge would exceed that of the inner, and this excess of velocity on one side would give the newly formed spheroid a rotation on its axis. It is obvious that this process might be repeated again and again with the same stratum, the successive spheroids revolving in continually narrower orbits, till at last the nebula is replaced by a system of compact bodies. Each separated spheroid might in the earliest stage of its formation throw off one or more fragments to become satellites. Thus, in conformity with physical laws, the solar system might have been formed from nebulous matter.

The consequences of rapid rotation on matter free to move and inclined to cohere, clearly forseen by Laplace, were experimentally verified and exhibited by M. Plateau. Oil floats on water because specifically lighter; but if spirits of wine be added to the water till the specific gravity of the mixture be reduced to equality with that of the oil, the latter will sink in the water as a globular mass and remain suspended in it without any tendency to move up or down. If then the vessel containing the water be made to revolve rapidly, the globular mass of oil becomes oblate, spreads out in the plane of rotation, and with increased velocity throws off globules which rotate and revolve round the central mass.

M. de Laplace, who looked at every thing with the eye of a mathematician, did not omit to calculate the probability of the solar system's origination from a nebula in the manner just described—or rather the improbability of the supposition that all the perfectly concordant movements of the system, rotating and revolving (he reckoned 43), were created separately and not connected together. He thence concluded the probability of their simultaneous origin to be as 200 billions to 1. But the revolutions alone of the Asteroids and of the planet Neptune with its satellites, since discovered, increase the number of the harmonious movements to 188. It seems to countenance the nebular hypothesis that the remotest planets, formed of the most volatile and rapidly moving matter, are also the largest and least dense; while the heaviest, of less size, are near the centre. It the motion had the effect of sorting the materials according to their specific gravities, there would probably be between the light and heavy, a circle of heterogeneous less cohesive material, of which the Asteroids give some indication.

The mechanical sufficiency of this hypothesis has been established by experiment; but its possibility has been contested on chemical grounds by a high authority (E. Bischof), who objects that the heat produced from the conversion of nebulous into solid matter would suffice to volatilize all. This is equivalent to asserting that under no circumstances can such condensation take place, which is clearly incorrect. When the condensing force (gravitation) is constant, and the dispersive force (evolved heat) transient, the former must surely come off victorious. The difficulties imputed to the hypothesis belong in truth only to the misconceptions of prejudiced learners. Bischof seems to have assumed that the supposed solidification of the globe or globes was instantaneous. It is often said that our earth was once in a fluid state through heat; he understood as much, and reasoned accordingly. But neither Kant nor Laplace ever hinted at a sudden change of state; and Herschel clearly admitted the agency of time. There is no reason to believe that the earth was ever a mass of melted mineral. We can believe that the process of solidification was, at the first, attended with a struggle and with intense heat, that the nucleus of the earth may have been, and may still be, fluid, that solidification then proceeded faster than aggregation, so that most material fell in the form of hot dust; and it is obvious that if the solidified nebular matter, all revolving as at first, fell by the force and under the guidance of gravitation, the earth's figure would necessarily conform to the laws of gravitation. It is not necessary to suppose it once fluid in order to explain why its figure is accommodated to its rotatory movement.

CHAPTER II.

The Earth.—Early Opinions as to its Figure.—Found to be a Globe.—Just Views of Aristarchus—why not adopted.—Motions of the Earth reflected from the Heavens.—Epicycles.—Copernicus.—Kepler and his Laws.—Newton—his Discovery of Universal Gravitation.—The Movement in Ecliptic Orbitse xplained.—The Earth's Orbit, Dimensions &c.—The Plane of the Elliptic.—Constancy of the Earth's Axis.—Revolution in the Orbit.—Time and Seasons.—Equality of Rotation.—Sidereal and Solar time.—Perturbations.—Division of Time.—Origin of the Week.

The earth, which, viewed in its place in the universe, appears but as an atom, is to uninstructed man a boundless world. Its early inhabitants have everywhere believed it to be collectively a great plain, of which they occupied the middle point. Thus, Delphi was thought by the Greeks to be at the middle of the earth; and the same distinction was claimed, at a much later date, by Sultan Bello for Sokatú, in the heart of Africa. The ancient belief still lives traditionally in the language of the Chinese, who call their country the Middle Kingdom.

It could hardly be expected of those who first speculated on the nature and figure of the earth, that they should at once recognize in it the surface of a globe, the only surface that can be perfectly uniform with all parts alike and without sensible boundary. The most difficult points to be decided were those that regarded its support and its limits. On the shield of Achilles, described by Homer, the ocean, forming the rim, was seen flowing round the earth in the middle. That the sea which so often bounds the land should be also supposed to encompass the whole earth, is natural enough; and in the case of the shield such a supposition was convenient. But the poet's language ought not to be considered as expressing an article of philosophic faith, or even the current opinion of his time.

Though the acute Greeks never discovered the ends of the earth, they saw reason to doubt its circular figure. Herodotus reprehends those who taught that the earth has an equal extension in all directions. The contrary, he thought, was to be inferred from experience. Let it be remarked that the countries best known to the Greeks, and most frequented by them, lay nearly under the meridian where extremes of climate occur at the least distance from each other. The northern shores of the Black Sea have a winter like that of the Polar circle, while in Africa at a little distance from the coast begin the deserts which give warning of the approach to the Torrid Zone. Diodorus estimates the distance between winter and perpetual summer, in Scythia and Upper Egypt respectively, at only a month's voyage. But while the habitable earth seemed clearly confined within narrow limits in the direction from north to south, it offered no indication of such a limit to the east or west. This latter direction, therefore, came to be considered as that of the earth's length, while the dimension along the meridian, or N. and S., was its breadth; and this mode of speaking still remains to us in the terms Longitude and Latitude. Among the circumstances which stimulated the commercial enterprise of the early Greeks, and awakened their faculties, it ought not to be overlooked that they occupied a position between widely different climates, accessible by sea and at no great distance.

The history of ancient science, which is indeed little better than a collection of anecdotes made by writers who had little respect for science, leaves us ignorant of the name of him who first demonstrated the sphericity of the earth. This doctrine is plainly enunciated by Plato and Aristotle, whose powerful understandings probably selected it for its real merits from the crowd of conflicting opinions. The most obvious and popular arguments in favour of the sphericity of the earth must have soon made some impression on the Greeks. Dwelling on small islands and sea coasts, they must have observed that the top of a ship's mast first becomes visible on the horizon, and that the hull rises gradually to view. As they returned homeward from the sea, they first descried the temple on the hill top, then the trees apparently rising from the water, and finally the cliff beneath the trees. They could not have failed to perceive that the horizon at sea is always a circle. Habitually keeping watch from high rocks, they must have been aware of the change made in the horizon by elevation; and voyaging constantly back and forward between

Asia Minor and Egypt, they must have observed how a course from N. to S., or in the contrary direction, affects the altitude of the stars. To these arguments Aristotle added the observation that the section of the earth's shadow, seen in eclipses of the moon, is always circular.

A little more than a century after Aristotle, Aristarchus of Samos promulgated a theory which appears to have been in all essential points identical with that of Copernicus. He supposed that the earth, rotating on its axis, revolves in an orbit round the sun fixed in the centre, and that the stars are infinitely distant. Now, remarkable in all respects as was this early approach to the truth, the most surprising circumstance connected with it appears at first sight to be its total want of success among a people fond of novelty and discussion, and of eminently keen intellect. How did it come to pass that the same discovery which startled Europe in the 15th century made no impression whatever on the disciples or contemporaries of Euclid and Archimedes? The cause of their apparent listlessness may perhaps be found in the immaturity of astronomical knowledge, which rendered quite conclusive Aristotle's sentence, that "since there is no parallax of the stars, the earth must be fixed in the centre." The imperfection of the evidence of the senses in such a case was not at that time suspected. Archimedes, who reports the theory of Aristarchus, treats as a manifest mistake the statement that the earth's orbit is to the distance of the stars as the centre of a circle (a mere point) to the circumference; whereas the fact is that the angle under which the radius of the earth's orbit is seen from the stars, or their annual parallax (and Aristotle had in view only the horizontal parallax), is but a fraction of a second, which is but a sixtieth of the smallest point distinctly visible to the naked eye. The apparent absurdity of the theory propounded by Aristarchus lay therefore entirely in the stupendous character of the truths proclaimed, and the incalculable magnitude which it assigned to the universe.

The motions of the earth may be read in the heavens, since they necessarily affect the apparent places of the other bodies of the solar system, whose visible courses are compounded of motions partly absolute or real, partly relative or apparent. But until the whole mechanism of the heavens be perfectly understood, it is impossible to trace with certainty the working of any single portion of it. Centuries were required to collect the observations out of which has grown the most complete of sciences, Modern Astronomy. But the inductive method was too slow for the Greeks, and they looked less to nature than to their own ingenuity for an explanation of the movements of the planetary bodies. These they contrived to imitate by means of cycles and epicycles, as already described (p. 4), a contrivance which, offering boundless resources, induced them to go on continually seeking improvement by adding new wheel-work to the celestial spheres. As the machinery grows complex, it grows dear to the inventor, who can never return from his assorted epicycles to the simple truth.

This erroneous system at length gave way with little resistence to that of Copernicus, who taught that the earth is a planet revolving about the central body, the sun. Why the philosopher of Thorn succeeded in the cause wherein he of Samos totally failed is not immediately obvious. It may be that the contrast between the simplicity of nature and the complexity of the Ptolemaic system, old and still imperfect, grew daily less favourable to the latter. The invention of printing had made a great change in the balance of power between the common sense of mankind and the prejudices of the schools.

Epicycles were completely banished from Astronomy by Kepler, who, from a careful study of the orbit of Mars, concluded that every planetary orbit is an ellipse, and announced with his discovery the following laws, which now bear his name:—

1. The orbits of the planets are ellipses, one focus of which, in each case, is occupied by the Sun.

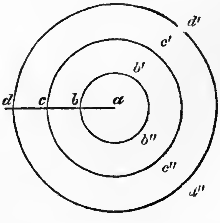
2. The areas described by the radius vector of the planet (that is, the line joining the sun and planet) are proportional to the times of describing them; therefore equal areas are described in equal times.

3. The squares of the times of revolution are as the cubes of the major axis of the orbits.

With respect to the second law, let it be observed that, in order that an area be invariable, it is necessary that its dimensions, *i. e.* length and breadth, either be invariable or shall vary inversely, the one increasing as the other diminishes. As the radius therefore increases in length, it describes a shorter arc or moves with less velocity.

It now only remained to find the cause of these laws, or to reveal the principle that controls all the phenomena of the heavens and gives them the completeness and unity of mathematical truth. This was done by Sir Isaac Newton, whose discovery of universal gravitation, the greatest feat ever achieved by the human intellect, not only demonstrates the order and harmony prevailing in the heavens, but points out also the causes of seeming disorder and its limits. It has proved to be, not so much the discovery of a system, as of a fountain of truth; and by enabling the calculator, in many instances, to outstrip in his researches the most diligent observer, it caused that emulation between theory and practice which has ultimately rendered astronomy the most marvellously perfect of the sciences. The main principle of the Newtonian system is as follows:—Every particle of matter attracts every other particle with a force proportional to its mass, *i. e.* its volume and density combined, and varying inversely as the square, or in the duplicate ratio, of its distance. If we suppose a force to emanate from any point (a, fig. 12) in all directions throughout a plane without change or abatement, then as it spreads in larger circles, being still the same force in each, it must vary at every point inversely as the area of the circle in which it lies and over which it is diffused, or as the square of its distance from a. If ab, bc, and cd be equal, then the areas of the circles $bb'b''$, $cc'c''$, and $dd'd''$ will be in the ratios of the squares of their diameters, or as 1, 4, and 9, and the force at d will be a ninth, that at c a fourth of that at b; the force at b will be to that concentrated at a as the point a to the circle $bb'b''$. Without this principle of universal gravitation there could be no fixedness or order in the universe. To the centrifugal force that moves the planets it adds also a centripetal force; and these

Fig. 12.



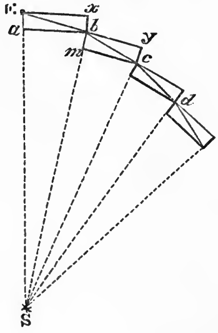
forces are so balanced that the paths of the revolving bodies, under the law above described, must always be elliptical.

Gravitation is measured by the velocity imparted by it to falling bodies. The weight of a body is its gravity combined with its mass. But gravitation considered apart from mass is the same in all bodies. A feather, a ball of cotton, a lump of lead, and a piece of gold, all fall together with the same velocity in the receiver of an air-pump, where the light bodies meet no resistance from the air. That velocity, in a body falling from a state of rest and continually accelerated, is, in our latitude, 16 feet 1 inch in a second of time; but converted into the more convenient form of uniform velocity, double that distance, or 32 feet 2 inches in a second. This is the effect of gravitation acting from the centre of the earth, or from a distance of 3924 miles. The force that acts on the moon and the planets is exactly the same, modified by the law above enunciated; that is to say, the space through which the moon would be drawn with uniform velocity to the earth in a second, is to 32 feet 2 inches inversely as the square of the moon's distance (238,793 miles) to the square of the earth's radius (3924 miles). Where there exists overwhelming power, as the attraction of the sun on the planets, or of the earth on bodies at its surface, feebler attractions are little heeded. The stronger force must be obeyed. But yet by cancelling the influence of weight, as will be seen further on, the mutual attraction of bodies on the surface of the earth may be rendered manifest.

The earth, viewed in the light of the Newtonian theory, is a spheroid revolving round the sun at a mean distance of 91,600,000 miles. Its orbital motion is the resultant of two forces, viz., first, that exercised by the sun's attraction, and, secondly, a force acting at right angles to the preceding or as a tangent to the orbit. The physical cause of the latter force is not apparent; but when it is considered that a similar force acts on all the planets and their satellites, in the same direction and nearly in the same plane, it seems reasonable to conclude that they were, in the first instance, all impelled by the same force, revolving together in a coherent mass, on the breaking of which, loss of coherence was made good by the attraction of the centre.

Let us now look at the construction of a planetary orbit. Suppose E to be the earth (fig. 13), E*x* the distance which it would be driven by the tangential force in a second, and E*a* the comparatively small distance which the attraction of the sun (S) would draw it in the same time, the course given to it by these combined forces would evidently be E*b*; for the next second the tangential force would be *by*, that of attraction *bm*, and thus in two seconds the earth would arrive at *c*, and in three seconds in like manner at *d*. A continual flexure of its course would thus be produced by the central attraction. The tangential force is constant, the attraction varies inversely as the square of the distance; consequently, if the planet approaches the sun its moving force increases, it proceeds with greater velocity in a less curved path, and so increasing its distance from the sun, loses force and velocity and returns to its first position. Increase of velocity is checked by removal from the sun and consequent loss of the attractive force; loss of velocity causes approach to the sun, and is remedied by the consequence of increased attraction. What has been here demonstrated is applicable to any body revolving round a centre the attraction of which varies in the inverse duplicate ratio of its distance.

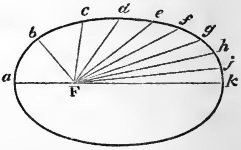
Fig. 13.



The radius of the earth's orbit is, as above stated, nearly ninety-two millions of miles. This is in truth the half of the major axis of the ellipse. But the sun being in one of the foci, and the eccentricity or distance between the middle point and a focus of the ellipse being about one sixtieth of the mean radius, the greatest distances of the sun from the opposite extremities of that axis are as 1·01679 to 0·98321.

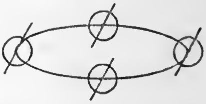
The plane of the orbit extending between the earth and the sun is called the plane of the ecliptic, being the plane in which all eclipses of the sun and moon must take place. The earth describing its orbit in a year moves at the rate of 68040 miles in an hour, or nearly 18 miles in a second. But, in truth, between the apsides or extremities of the major axis, and symmetrically on both sides of it, the velocity of revolution varies at every step. At a greater distance from the sun the revolving body looses speed, and again, when near the sun, acquires velocity, the areas *a*F*b*, *b*F*c*, *c*F*d*, &c., or distances *ab*, *bc*, *cd*, &c. (fig. 14) being all described in equal times, so as to make good Kepler's second law, as to the constancy of the areas described by the radius vector, the area lost in one direction (distance from the sun) being made up in the other direction by velocity.

Fig. 14



While the earth revolves round the sun, it at the same time rotates on its axis, which is inclined to the plane of the ecliptic at an angle of 66° 33′. The momentum of a body rotating tends to perpetuate that motion, persisting in it with a force proportional to its weight and velocity. But the force of rotation of a globe like the earth, nearly 8000 miles in diameter, and spinning round at the rate of more than 17 miles in a minute, is quite sufficient to render the position of its axis incapable of change. That position is maintained by the whole force of rotation. The earth's axis therefore, though it changes place, never changes its position, inasmuch as it moves parallel to itself, making always the same angle with the plane of its orbit, and points in the same direction to the heavens (fig. 15). As the earth rotates from W. to E., the heavens seem to move in the opposite direction, and their visible pole is immovable. It is in fact a reflexion of the pole of the earth; and the fact that the earth's axis while carried round an immense orbit, seems invariably directed to the same point in the heavens, is a proof of the immeasurable distance of the latter, a distance so great that the orbit becomes in respect of it an imperceptible magnitude.

Fig. 15.



Since the earth's axis remains always parallel to itself, it must in the orbital revolution present itself under different aspects to the sun; and as it makes an angle of 66° 33′ with the ecliptic or plane of its orbit (P *c* S, fig. 16) this angle must be at times turned towards the central body and at other times from it, the complementary angle 113° 27′ in the latter case (S *c* P′) facing the sun. Thus the circle of light and darkness lies obliquely to the axis, passing beyond and falling short of the poles alternately, in periods of half a year. Intermediate between these positions it presents a right angle to the sun, and the illuminated hemisphere reaches both poles (fig. 17). Thus the vicissitudes of day and night, of light and darkness, resulting from the rotation of the earth, are rendered various by the inclination of the earth's axis.

Fig. 16.

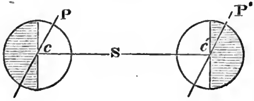


Fig. 17.

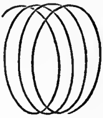
The earth while performing one rotation advances also in its orbit at the rate of 1134 miles in a minute or 1,632,960 miles in a day; and the consequence of this change of place is the altered position of the sun in the heavens, which seems in the mean to have advanced about 59′ 8″·33. The time of rotation required to overtake the sun is the difference between the sidereal and the solar day. But the sun's apparent motion, or rather the motion of the earth in its orbit, is not uniform. It is slower in one half of its orbit than in the other—losing velocity when it recedes from, and acquiring it as it approaches the sun; and besides, motions really equal do not always appear so, on account either of distance or obliquity. Hence solar time is variable; yet it has advantages which make it indispensable as a measure of duration. It must therefore be regulated. Consequently the solar year is divided into equal days, hours, &c., the parts of mean solar time; while the sun's variations and irregularities are calculated and reduced to a table showing the difference during the year between solar time, derived from the sun's movements, and mean time, found by correcting the preceding. This difference is called the Equation of time. Gravitation or the fall of heavy bodies affords a very constant measure of time, as in the hour-glass, the clepsydra, the pendulum, &c.; but these, accurate as they may be, can only be regarded only as instruments amenable to some higher test of accuracy, for which it is necessary to have recourse to the stars or sidereal time.

Of the various motions in the heavens just described, only one, the earth's rotation, seems perfectly uniform; and there is no ground for supposing it liable to disturbance. It has been frequently suggested, in order to account for past changes of climate, that the earth's axis of rotation has been changed. Some have held that it has been frequently changed. But it is certainly venturing very far in assumption to suppose that the rotation of the globe could be suddenly stopped or changed by a shock without breaking the whole structure to pieces. Besides, the advocates of a changed axis have overlooked the fact that no change in the direction of rotation could take place without some loss of velocity. Whatever velocity of rotation the earth actually has must be either its original velocity or a remnant of it; and the remnant must be very small if the change has been frequent. But when we look at the other planets, compare their rates of rotation, and judge by analogy, we must conclude that the axis and rotation of the earth have never changed. If the earth were to contract, the velocity of rotation would be thereby increased; the dilatation of the globe, on the other hand, would reduce it. But from various ancient observations compared with those made at the present day, astronomers are enabled to conclude that within the last 2000 years the length of the day has not altered to the extent of a second.

The sidereal time therefore, or the time that elapses from the passage of a star over the meridian till its next return to that meridian, is the true unit of time. It is equal to 23 hours 56 minutes 4·09 seconds of mean solar time; or if the sidereal day be divided into 24 hours, the mean solar day will contain 24 hours 3 minutes 55·909 seconds of sidereal time.

The earth is attracted, not only by the sun, but by all the planets; and the regularity of its movements is thereby much affected. Planetary disturbance gives rise to very complicated problems. It is in consequence of such perturbation that hardly any element of a planetary orbit is perfectly constant. The orbit never returns into itself, but takes a new path with some change of figure (fig. 18). In the case of the earth, the cycle of the seasons does not correspond precisely to the revolution in the orbit. The angle at which the major axis cuts the line joining the equinoctial points is continually changing; and thus the sun, considered as the leader of the seasons, seems to make the circuit of the orbit in the long course of 20984 years. The perihelion, or point of the orbit nearest to the sun, is now reached by the earth in the winter of the northern hemisphere (11th January); but at the end of 10492 years the same position will not be reached by the earth till midsummer. The eccentricity of the orbit decreases for a long period, and then again increases. All these variations in the planetary world are produced by attractions which, as they proceed from revolving bodies, continually change their direction. Consequently when, after a long period, all these bodies may be supposed to have performed complete revolutions, the disturbing forces having operated in all directions and annulled each other, they will leave the system nearly as they found it at the beginning.

Fig. 18.



Thus it appears that there is as little of absolute fixedness in the heavens as there is of that perfect figure the circle. The perfection of the planetary system lies not in rigour, but in liberty. It is a flexible perfection, manifested in physical laws, which, by a perpetual play of adjustment and equipoise, keep imperfection within narrow limits.

In an account of the relations of the earth to the heavens, it ought not to be omitted that to the latter is due the division and measuring of time. To mankind in its primitive condition, the heavens presented no more interesting object of observation than the moon, as it goes through all its phases in a convenient and well-marked period. The month or lunation therefore, being the time between two successive new moons, was probably everywhere the first period established in the calendar. But it was seen also that twelve lunations (354 days) nearly correspond with the solar period and the renewal of vegetation; the

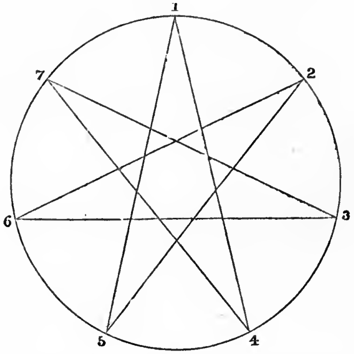
Lunar year therefore, consisting of 12 months, was in early times generally adopted. But further experience proving the inconvenience of a year not strictly in accordance with the sun and seasons, the solar year of 365¼ days came into use as astronomical science attained precision; and the calendar founded on it is now received by all civilized nations. In adopting the Solar instead of the Lunar year, the convenient division into twelve parts was retained, though these, being necessarily lengthened beyond the time of a lunation or 29½ days, no longer coincide with the periods originally and properly called moons or months.

The week of seven days seems to have been in use from the earliest ages in all parts of the world. It was found in China, India, and Peru, as well as among the Hebrews, Arabs, and other Semitic races. To the Greeks and Romans, however, it remained till a comparatively late age quite unknown. Adopted by the Christians, it spread with the new faith from Egypt through the rest of the Roman empire, and was first introduced to measure time in affairs of civil life under Constantine. There can be no doubt that the week originated in the subdivision of the lunation. It was the moon's quarter, the round number 7 being naturally substituted for 7⅜, and no attempt was made to reconcile the parts with the whole or to remedy the failure of coincidence, because there was no need of coincidence, and no seasons were disturbed by the occasionally disordered relations of weeks and lunations.

It is very remarkable that weeks of seven days, unknown to the Greeks and Romans, and brought into Europe with Christianity, should bear in the names of the days the stamp of Paganism. The days of our week are dedicated by name to the Sun, the Moon, Teuth (the Saxon Mars), Woden (the Saxon Mercury), Thor (the Saxon Jupiter), Friga (the Saxon Venus), and Saturn. The way they came to receive those names translated from Latin or the language of the Church, may be thus briefly explained:—The Egyptian astrologers or almanac-makers supposed every hour of the day to be under the influence of one of the seven planets, which, according to Ptolemy's system, stood in this order—1. Saturn, 2. Jupiter, 3. Mars, 4. the Sun,

5. Venus, 6. Mercury, and 7. the Moon. The first hour was under the influence of Saturn, and to Saturn therefore the day was dedicated. Then the other planets had each its hour, the eighth hour of course again falling to Saturn as well as the fifteenth and twenty-second. Consequently the twenty-fifth hour or the first of the following day fell to the heavenly body that followed as third after Saturn; that was the Sun, to which therefore that day was dedicated, and in like manner the next day took the name of the planet third on the list from the Sun. If, then, the names of the seven planets be placed in order in a ring (fig. 19), and beginning with Saturn, we draw lines joining each with the third that follows it, we shall find that these lines guide us to the names in the order of the days of the week. The names used by the astrologers soon grew popular; and being popular and familiar, they gave no offence to the Christians, particularly as the name of the Lord's-day, Sunday, might be understood figuratively; for, as St. Ambrosius says, "the Lord came as *a Rising Sun* to disperse darkness."

Fig. 19.



CHAPTER III.

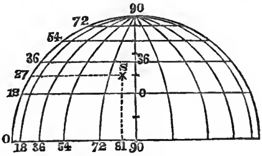
Ancient observation of the Heavens.—Description of the Celestial Sphere—its Divisions transferred to the Earth.—The Sphericity of the Earth recognized—Its Magnitude conjectured.—Eratosthenes, his measurement of a degree—his method revived by Fresnel in the 17th century.—Snell's attempted triangulation.—Geodetic Surveys, France, Great Britain, India, Russia, &c.—Newton's Work.—Effects of Rotation on the Earth's figure.—Irregularities of Gravitation at the Surface.—Increase of Gravity from the Equator to the Pole—and of the length of Degrees.—Figure and size of the Earth determined.—The Pendulum as a means of measuring Gravitation.—The Attraction of Mountains.—Schehallien.—The Himâlaya.—The Torsion Balance.—The Specific Density of the Earth.

To the watchful Greeks on hill-tops, and to the shepherds of Assyrian plains, the stars and revolving heavens must have been deeply interesting objects. The stars were soon grouped, for facility of reference, into imaginary figures or constellations. The central portion of the heavens about the paths of the sun and planets, whither observation was most frequently directed, was the first to be marked out in this way ; and a Zodiac or figured zone of the heavens was known to almost every ancient nation. Attention was directed also to the polar region, where the stars perform their circuits above the horizon, and "the bear," as Homer sings, "alone never bathes in the streams of ocean." Nor did the little bear, anciently called the Dog, and the remarkable star named the Cynosure (*κύνος οὐρὰ*) or Dog's tail, known at the present day as the Pole-star, round which the whole heavens turn, escape notice.

But the contemplative spirit admires the constancy of the heavens more than their fancied imagery. The pole is immovable ; the stars wheel round it in circles, increasing with their distance from it, the whole sphere revolving apparently on a fixed axis. The greatest of these circles therefore lies in the middle between the poles, or 90 degrees from the visible pole. This circle, the Equator, as real as any mathematical conception can be, and marked out by the stars lying about it, was seen to be immutable in position. Again, the path of the sun, from which the planets never far depart, crosses the equator at an angle that seemed invariable. Thus the attentive observation of the revolving heavens led to the belief in their perfect immutability. The spheres were supposed to be made of crystal, that is to say, they were solid and transparent. At a later date the supporting framework was vaguely styled the Firmament.

The recognition of the constancy of the heavens was naturally followed by the desire to mark them out by well-defined lines in such a way that the exact place of any object in them might be conveniently noted and expressed. This was easily effected. The equator was supposed to be divided into 360 parts or degrees, by great circles, that is to say, circles of the sphere passing through its centre and also through the pole. By these hour-circles, as they were called, the surface of the sphere was divided into long strips or segments from pole to pole, each bearing the number of the degree at which it terminated on the equator. For the starting-point of the numeration a fixed point was necessary, and this was the vernal equinox, or the point where the sun moving in the ecliptic, crosses the equator in spring. Thus the right ascension or distance of any star from the zero of the numeration, measured on any circle parallel to the equator, could be determined by noting the circle that passed through it from the pole to the equator. But again, circles of declination were drawn parallel to the equator, across the hour-circles; and these latter being also divided into degrees, the declination of the star or its distance from the equator could be thus ascertained. We know the exact place of a star (S, fig. 20) when we know its declination or distance (27°) from the equator measured on the hour-circle passing through it, and also its right ascension (81°), or the distance of that hour-circle from the zero-point on the equator. This point, a star in the constellation Aries, originally selected because it marked the crossing of the ecliptic over the equator, is at the present day removed by secular changes several degrees from the actual vernal equinox.

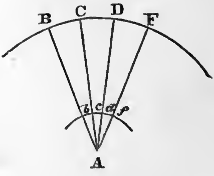
Fig. 20.



The advantages of this mode of marking positions in the heavens were so striking as to prompt the wish that the earth might, from its relation to the whole system, be enabled to partake of them. It was observed that in going along the meridian from north to south, or in the opposite direction, the heavens show a change of aspect exactly corresponding to the change of place, the zenith or point of the heavens vertically above the observer moving from him. If he goes to the north, the star that marked the zenith of his starting-point appears to the south of his new zenith, and to the north if he goes southwards. In fact the change in the polar distance of his zenith, measured in degrees of a great circle, is exactly the same as the distance gone over by him, measured in terrestrial degrees. It was known that Canopus, the brightest star of the southern hemisphere, and in Egypt a very attractive object, was in Crete seen near the horizon with diminished splendour, in Rhodes only from the highest summits, and that on the coast of Asia Minor it was lost wholly to view. Let it be observed that on an hour-circle or line drawn from the pole N. and S. to the equator, only one point can ever be in the zenith of any one place. But on a circle of declination from E. to W. every point passes in turn through the same zenith; consequently the change of zenith attending progress to the east or west corresponds with the time when a particular point of the circle arrives at the zenith, and the difference of time between two places is less easily found than that of their zenith distances.

The fact that change of zenith distance (from the celestial pole) accompanies change of place on the earth, and that these two changes, measured on straight lines from the pole to the equator, are strictly proportional, affords at once a presumption that the earth is a globe. If from A (fig. 21), the common centre of two concentric circles, the rays A B, A C, A D, A F be drawn to the circumference of the outer one, they will cut both circumferences in the same proportion. If B C, C D, and D F be equal, then bc, cd, and df will also be equal. If B C be

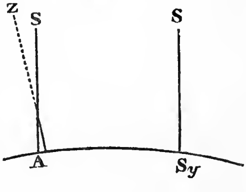
Fig. 21.



greater than C D, *b c* will exceed *c d* in the same proportion. But it will be impossible to draw across the rays A B, A C, A D, and A F, any line not the arc of a concentric circle, the segments of which will consecutively represent the proportions of the segments B C, C D, and D F. If, therefore, marching northwards we mark the places where the zenith distance is successively diminished by one degree, and if those places are found on measurement to be separated by equal intervals, we are justified in concluding that they are points in the surface of a sphere.

Now if it be once admitted that the earth is a sphere, the centre of which is also the centre of the visible celestial sphere, then it follows that the arc of the earth's meridian, which makes a change of one degree or the 360th part of the circumference in zenith distance, must be itself a degree, or 360th part of the earth's circumference. By measuring that arc, therefore, we learn the circumference and diameter, in short the dimensions of our globe. The first who made practical application of this inference and attempted to measure the earth was Eratosthenes, of Alexandria, who flourished about the end of the third century, B.C. He had learned that at Syene (*Sy*, fig. 22), at the southern limit of Egypt, the sun's rays on the longest day illumined the bottom of a deep well, whence he concluded that at the summer solstice the sun (S) was in the zenith of Syene. But he found also by observation of shadows that at Alexandria the sun at the same time was one 50th of the circumference (7° 12′) from the zenith. He therefore concluded the distance between Syene and Alexandria, estimated at 5000 stadia, to be a 50th of the earth's circumference, which was accordingly 250,000 stadia. This exceeded the truth by about a seventh, the details of the calculation being all inexact. Syene was not on the same meridian as Alexandria, nor was it exactly under the tropic; and the distance between the two places estimated in round numbers had no pretensions to correctness. Yet to Eratosthenes belongs the merit of having first applied the

Fig. 22.

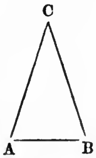


right principle in the problem of measuring the earth, and in so doing of having made a better approximation to the truth than his immediate followers and imitators, Posidonius and Ptolemy. Of this attempt Pliny says, "Improbum ausum, verum ita subtili argumentatione comprehensum ut pudeat non credere." "A wanton exploit, yet devised with such depth of reason that one is loath to disbelieve it." It is curious to find the Roman writer affecting to fear the impiety of bold intellectual research. This fear of innovation is handed down from age to age, though each succeeding generation readily acknowledges the groundlessness of past alarms.

Many centuries elapsed before any decided improvement was made in the process recommended by Eratosthenes. It involved, it is easy to perceive, two totally different operations; first, exact observation of the heavens, and, secondly, an equally exact measurement of the ground lying between the places thus determined. The great progress of Astronomy after Copernicus, due to the labours of Tycho Brahé, Kepler, and Galileo, together with the invention of telescopes, had already in the 17th century brought observation of the heavens to a perfection of which the ancients had no conception. As to measuring the ground for great distances in a straight line and with extreme precision, it was in a populous country obviously impracticable. Fernel, a very eminent physician at the court of Louis XI., having in view the problem proposed by Eratosthenes, measured in 1524 a degree from Paris to Amiens, by the revolution of a wheel; and Norwood in England did the same thing between London and York; but though both were deemed successful in their day, science has paid little attention to their labours.

It was about 1615 that Willebrod Snell, of Leyden, proposed to survey a province of Holland by means of triangulation. This happy thought, which has raised Geodesy, or the science of Land-surveying, to perfection, deserves here a few lines of explanation. Since the three angles of any triangle are equal to two right angles or 180 degrees, it follows that if we know two of them we can find thence the third also. When we know the angles of a triangle (that is to say, their measure in degrees), we learn also the mutual proportions of its sides though not their absolute length. Yet in this case, if the length of one side be known, the lengths of the others are easily derived from it. Consequently when two angles of a triangle are known, and the length of one side, with the position of this side with respect to the known angles, the problem is solved, and we learn the lengths and positions of the other two sides. Suppose, then, that A, B, and C (fig. 23) are three places visible from each other, marked by church towers or by poles fixed on hill-tops, for the points to be observed ought to be precisely fixed; from A may be observed the angular distance between B and C, or the angle B A C; from B in like manner may be observed the angle A B C; from these may be deduced the angle A C B, which completes the sum of 180 degrees, or by observing it the correctness of the preceding operations may be tested. If the distance A B be now measured, the triangle is known in all respects. But the sides A C and C B, the lengths of which have been thus learned, may belong to other triangles lying further off, and thus chains of triangles covering a kingdom may be all calculated and the lengths of their sides derived from the measurement of a single line.

Fig. 23.



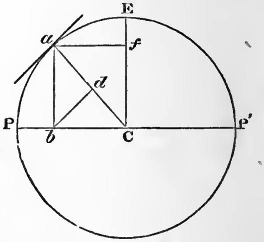
It is obvious that this mode of proceeding greatly excels the system of measurement adopted for ordinary land-surveying both in facility and correctness. The observation of angles from towers or elevated positions may be made quickly and repeatedly, and with the finest instruments; and owing to the strictness and harmony of mathematical deductions, they serve to test each other, so that no error can escape detection; and in the work of calculation the greatest precision is attainable. The triangles constitute a framework, which may be filled with details obtained in the usual way, and the larger the triangle, the more summary is the process and the more secure from error. The measured line from which the rest are calculated is called the base. A level plane of sufficient extent and free from impediments is selected for it, and no pains are spared to obtain its length with the utmost precision. In the survey of the United Kingdom the sides of some of the triangles exceeded 100 miles. In general two bases at least are measured, connected with different parts of the work to check each other. If the measured length of each agrees with its length calculated from the other, there can be no error in the whole extent of triangulation involved in the calculation. In the triangulation of the British Isles, two of the principal bases measured were, that on Hounslow Heath 27406·190 feet in length (about 5 miles), and that near Lough Foyle in Ireland 41640·887 feet, or nearly 8 miles in length. The differences between the measured and the calculated lengths of these were respectively but 0·173 and 0·216 of a foot, about 2 inches in the former, and nearly 2½ inches in the latter. The whole error in the length of the kingdom is probably less than 3 feet. The mountains of Wales and Westmoreland were connected with those on the western side of the Irish Sea by means of the Drummond light.

Snell carried his views into practice and measured by triangulation an arc of the meridian between Alcmaar and Bergen op Zoom. But his means were narrow; and in those days, when logarithms were as yet unknown, the labour of the calculations required for his undertaking was enormous. He never therefore advanced to completion, though he succeeded in pointing out to others the route to be pursued. The most laudable ambition of Louis XIV. was that of seeing his nation foremost in the career of science. This was his motive when he directed Picard to measure a degree between Paris and Amiens. He could not have hit upon one better qualified to realize his desire. To all the scientific learning of his time, Picard added comprehensive views, great zeal, and practical ability. He prepared to measure the required arc by triangulation, with advanced mathematical knowledge and with instruments far superior to any hitherto employed. His work, when completed in 1669, gave for the degree between Malvoisines, near Paris, and Amiens, 57,060 toises, or 364,850 feet, which was very near the truth, the errors or omissions in the details, detected by the riper science of the following centuries, having luckily compensated each other. This was in itself a remarkable step in the march of science; but it also indirectly aided an unexpected and much more important advance.

Newton was at this time engaged on his great work 'The Principles of Natural Philosophy.' His views were probably fully matured in 1667; but scrupulously exact, he met with a check in the application of his theory, which made him delay their publication. He held that the attraction of gravitation, which on the earth's surface impels bodies falling to the ground, is the same force which holds the moon in its orbit. The attraction in question he supposed to vary inversely as the square of the distance at which it acts. At the distance of the moon, therefore, or of sixty times the earth's semidiameter, its force would be $\frac{1}{3600}$ of that exerted at the earth's surface, where a body falling from a state of rest acquires in a second a velocity which carries it uniformly through 32 feet 2 inches. It remained then only to calculate the distance which the moon falls in a second to its orbit, from the rectilineal course in which it would continue were there no attraction. It is obvious that the most weighty element in this calculation was the moon's distance, or rather the earth's radius, by which that distance was measured. Now Newton, in estimating the size of the earth, had assumed the length of the degree to be 60 British miles (316,800 feet), or nearly a seventh less than the truth. His calculation therefore resulted in disappointment, and he doubted whether gravitation alone could account for the lunar motions. In 1681, however, he heard for the first time (so slow was the diffusion of scientific intelligence in those days) of the careful measurement of a degree in France by "one Picard." Having obtained the desired particulars, and being struck doubtless by their favourable aspect, he proceeded to recalculate the moon's fall to the earth; but overcome by emotion as he approached the wished-for result, he had to call in the aid of a friend to finish the work. His theory, then found to be completely confirmed, was in 1686 at length published.

It is manifest that, as the earth rotates on its axis, the centrifugal force generated by its rotation must be unequally distributed over its surface. When a weight fastened to a string is whirled round it forcibly stretches the string, because its tendency at every instant is to go off in a tangent to the circle to which the string confines it. This tendency to recede from the centre is called the centrifugal force, which in all cases increases with the velocity of the rotatory movement that gives birth to it. Now on the earth the velocity of rotation, and consequently the centrifugal force, is greatest where the circumference is greatest, that is, at the equator. At the pole there is no centrifugal force, because there is no circle of rotation, but only a point. Between the pole (P) and equator (E, fig. 24) it increases with the circle of rotation or its radius *a b*, which is in every case equal to the cosine of latitude. But the centrifugal force here spoken of acts entirely in the direction of the rotation, or perpendicular to the axis. At the equator, therefore, it is directly opposed to gravitation, the latter tending to the centre of the earth, the other from it. Here, therefore (at the equator), gravitation is diminished by the whole amount of centrifugal force. But at a distance from the equator, as at *a*, gravitation pointing to the centre of the earth and represented by *a* C, is not perpendicular to the axis, and therefore not directly opposed to centrifugal force, but makes with it an angle equal to the latitude of the place; and if the rotatory force *a b* be resolved into its horizontal and vertical components *b d* and *d a*, it will be seen that the latter, which stands directly opposed to gravitation, is to the whole *a b* as the cosine of latitude to radius. Thus it appears that the whole centrifugal forces varies as the cosine of latitude, and also that the vertical component of it, or that portion of it which counteracts gravity and which alone is often, though incorrectly, called the centrifugal force, varies in the same ratio; whence it follows that the diminution of gravity from the pole to the equator, or its variable element due to the centrifugal force, varies everywhere as the square of the cosine of latitude.

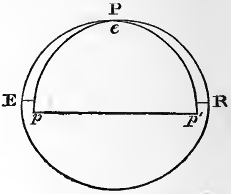
Fig. 24.



Since the diminution of gravitation resulting from the rotation of the earth is greatest at the equator, and decreases thence towards the poles, it follows that the sea, in order to establish equilibrium, must rise higher at the equator, where its gravity is least, than at the pole, where it has the greatest weight, and where the horizontal component of the force generated by rotation drives the sea towards the equatorial region. But the figure of the earth being determined by the surface of the sea, cannot be a perfect sphere, because were it even so formed in the first instance, its liquid covering would, under the influence of rotation, raise it at the equatorial region and depress it at the poles. Newton found that the centrifugal force at the equator is equal to the 289th part of gravity; and investigating the figure of the earth, on the provisional assumption that it is homogeneous or of equal density throughout, he concluded that it is a spheroid with a polar compression of $\frac{1}{230}$, that is to say, the polar is to the equatorial axis as 229 to 230.

The language ordinarily used, which assumes that the earth's attractive power resides in its centre, is totally erroneous. The attraction of a distant body may be conveniently assigned to its centre, because the resultant of the attractions of every atom in that body may be supposed to pass through or very near its centre. The attraction of the earth at its surface is obviously due to the whole globe, and not to its centre alone. Below the surface, and on Newton's supposition that the earth is homogeneous, gravitation diminishes in the same ratio as the distance from the centre, where it totally vanishes. It is certain, however, that the earth is not homogeneous, but increases in density towards the centre, and therefore gravitation does not immediately decrease below the surface, nor until the stratum above is sufficient to counteract the effect of approach to the denser centre. The modifications of gravitation on the earth may be briefly recapitulated. In consequence of rotation it is diminished at the equator by a 289th part, and the immediate effect of this is an adjustment of the figure of the terraqueous globe, the waters rising as their weight is diminished. But the attraction of a body proceeding from every point of it and not from a single point, must depend in some degree on its figure. Now on that account the compressed hemisphere of a spheroid attracts a body on its surface more powerfully than the more convex hemisphere; for it is a more compact mass, and its forces are collectively nearer to the surface, as is manifest when the convex is placed within the oblate hemisphere. The gravitation at P, due to the oblate hemisphere E P R, exceeds that at *e*

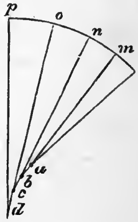
Fig. 25.



in the more convex hemisphere *pep* (fig. 25). On this account, as well as on that of the absence of centrifugal force, gravitation at the pole exceeds that at the equator by a 194th part, that is to say a body weighing 194 ℔s. at the pole would weigh 195 ℔s. at the equator.

From the compression of the polar and greater convexity of the equatorial regions, it follows that degrees of the earth's surface increase from the equator to the pole. A degree is the 360th part, or, rather, the angle subtended by that part, of the circumference of a circle. Now were the earth a perfect sphere, all lines vertical at its surface would pass through its centre; and those dividing an hour-circle of the heavens into equal parts would divide a terrestrial meridian in like manner. But since the earth is a compressed spheroid, and not a perfect sphere, lines vertical to its surface have not all a common centre, but converge further from the circumference as the convexity decreases, that is, towards the pole (see fig. 26), and consequently the terrestrial arc corresponding to a degree of the sphere increases from the equator towards the pole, because with increasing radius *a m*, *b n*, *c o*, *d p*, it marks in fact a degree of a greater circle. It caused some sensation therefore in the scientific world when De la Hire, having continued Picard's measurements to the north and south, announced in 1718 results adverse to Newton's conclusions. They were as follows:—

Fig. 26.



	toises.	feet.
The degree between Bourges and Paris......	57098	365,346.
,, ,, Paris and Amiens......	57060	365,103.
,, ,, Paris and Dunkirque...	56970	364,527.

From this it would appear that the measured degree decreases towards the north instead of increasing as theory required. But it was felt that the theory of gravitation and its consequences respecting the figure of the earth could not be shaken by a few discordant results obtained in middle latitudes; that to try it fairly by experiment, degrees ought to be measured under the equator and within the polar circle. The zeal of scientific inquiry was now fully awakened. Expeditions were sent to Peru in 1735 under Bouguer and La Condamine, the scene of whose labours lay in the elevated valleys of the Andes; and to Lapland, where Maupertuis (1736) measured his base upon the ice; the results obtained were:—

	Length of the degree.	
In Peru (mean lat. 1° 31′ 10″)……	56,737 toises	=363,038 feet.
In Lapland (mean lat. 66° 20′ 10″)	57,196 ,,	=365,774 ,,

Thus polar compression was satisfactorily proved. Since that time several triangulations of more or less extent have been executed, for the purposes of civil administration or to gratify scientific curiosity. Only four of them, however, need be here mentioned. Towards the end of the last century the French nation undertook that measurement of an arc of the meridian between Barcelona and Dunkerque, which had for its immediate object to determine the exact length of the quadrant (90°) of the globe, the ten millionth part of which was to be taken as the mètre or standard unit of measure. It was subsequently extended to the island of Formentera, near Minorca, thus embracing 12° 50′ of latitude. The further continuation of it to the Orkney Islands has never been published. The Triangulation of the British Islands was commenced in 1802, and attained in its progress a high degree of perfection. Its longest arc of the meridian, from the Scilly Islands to Shetland, has a length of 10° 57′ 54″ degrees. The Trigonometrical Survey of India, begun in 1825 at Punnæ, near Cape Comorin, has been continued to Kalianpoor, at the foot of the Himalaya, a distance of more than 21 degrees. Lastly, a chain of triangles has been carried across European Russia from Ismaîl, near the mouth of the Danube, to Fuglenæs in Finland, above 25 degrees. The Russians have also commenced geodetical operations in Asia; and some points have been fixed by them even in the Thian Shan Mountains, in the middle of the continent. One of these points was recently visited by British officers who accompanied Mr. Forsyth in his embassy to Turkestan. Thus some connexion has been established between the scientific labours of Russia and Great Britain. The following brief Table will suffice to show the tendency of the results obtained by these measurements, all but the first relating to the northern hemisphere.

Latitude. °	Length of a degree of the meridian.	Length of a degree of the parallel.
0	362,644 feet.	365,185 feet.
10	362,850 „	359,677 „
20	363,175 „	343,292 „
30	363,660 „	316,532 „
40	364,523 „	280,131 „
50	364,886 „	235,195 „
60	365,482 „	183,099 „
70	365,788 „	125,270 „
80	366,300 „	63,619 „
90	366,489 „	0 „

Though trigonometrical surveys all over the earth concur in the general conclusion that the degree lengthens and the earth grows oblate or compressed towards the poles, they do not agree in minute particulars, but abound in discrepancies not attributable to error. Hence it is impossible to unite them in any perfectly regular figure. But the earth is approximately represented by a spheroidal figure with a compression of nearly a $\frac{1}{299}$th; and the irregularities scattered over this spheroid are relatively so minute, that on a perfectly executed model, four feet in diameter, the eye could hardly detect them. The dimensions of the earth are, according to

	Bessel. miles.	Airy. miles.	Capt. Clarke. miles.
Equatorial Diameter...	7925·604	7925·648	7926·686 and 7924·826
Polar Diameter.........	7899·114	7899·170	7899·203
Polar Compression ...	26·471	26·478	

According to Capt. Clarke the equatorial section of the earth is also elliptical, its greatest and least diameters differing by nearly 2 miles. The vertices of the former are in 14° 23′ and 194° 23′ E., those of the latter in 104° 23′ and 284° 23′. Thus the compression varies round the axis, its limits being $\frac{1}{287\cdot5}$ and $\frac{1}{308\cdot3}$.

The measurement of a degree includes two very different operations. First, two points are found in the same meridian, the zeniths of which are exactly a degree asunder; and secondly, the distance between these points is ascertained by measurement or exact calculations founded on actual measurement. Now it is quite possible that though the figure of the earth were perfectly regular, its division into degrees might be rendered irregular by unequal gravitation. This irregular gravitation has been detected in the observatory of Edinburgh, in the Isle of Wight, and elsewhere in Great Britain. The plumb-line is irregular about Moscow, where there are no inequalities of surface to suggest an explanation. But the most remarkable instance of abnormal gravitation occurs at the southern base of the Himalaya Mountains. In consequence of it, we are told, the sea at Karachi, near the mouth of the Indus, is 514 feet above the sea at Cape Comorin, the line of level being raised to that extent by the attraction of the mountains.

The existence of local attractions, which disturb the vertical line and the true level, is fully proved by observations with the pendulum. A weight suspended by a cord, or, as the pendulum is usually constructed, a disk of metal attached to a slender wire and allowed to swing back and forward or to oscillate freely, is impelled by gravity alone; and for the purpose of measuring gravity it became important, as soon as Huyghens demonstrated that its oscillations in small arcs (not exceeding 4°) are all made in equal times, that the time of oscillation varies as the square of the length of the pendulum, and that the time of oscillation is to the time in which a body would fall from a state of rest down the length of the pendulum as the periphery of a circle to its diameter. We are thus enabled by observing the oscillations of any pendulum of known length and ascertaining their rate, to deduce from them the length of the pendulum that would in the same place beat exact seconds, and also how far a body would there fall in a second, or the force of gravitation.

It was already remarked in 1671, by Richer at Cayenne, that the pendulum that beats seconds in Paris is too slow near the equator and requires to be shortened. This phenomenon, which drew much attention at the time, was explained at once when

Newton showed that gravity decreases towards the equator. Since that time experiments with the pendulum have been made in all parts of the world; Capt. Kater improved the mode of using it, and Sir Edward Sabine carried it from the equator to Spitzbergen in lat. 83°. Its collective indications exhibit clearly the increase of gravity from the equator to the poles; but they prove also the existence of much irregularity arising from local causes and within very narrow limits. Indeed a competent authority has pronounced that the pendulum is rather a geological than a geographical instrument, by which we must understand that it indicates rather the attraction of the adjacent rocks than the gravitation of the earth. But it must be observed that in this respect all bodies close to the earth must resemble the pendulum. In the latitude of London the length of the seconds pendulum *in vacuo* and at the sea-level is 39·13929 inches.

At a height of a few miles above the earth a pendulum in a balloon would oscillate more slowly than at the surface of the ground, showing a decrease of gravity. But at the same elevation, on a mountain, it might move faster, because the mountain is an attracting mass and might add to the attraction of gravitation at its base. Thus the pendulum oscillates more quickly on the summit than at the base of Mount Ararat. Now if we could estimate correctly the dimensions and specific gravity of the mountain that accelerates the pendulum, and the distance of its centre, we might compare its attraction with that of the earth, since we know how they each act on the pendulum; and also the size of the earth and the distance of its centre. We might then deduce from the comparison of volumes and of masses the specific density of the earth. This was done by Carlini on Mount Cenis.

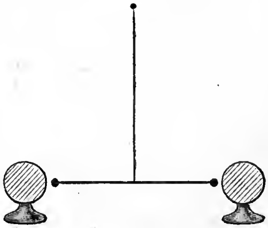
The same problem may be solved by means of any distinctly traceable source of irregular attraction. Suppose a mountain of granite running east and west (fig. 27), and two stations on the same meridian on its opposite sides, with the distance between them ascertained by measurement to be exactly 6060 feet, or 60 seconds of space, which is about equal to a geographical mile or minute. Now if observation of the

Fig. 27.

heavens or zenith distances were to make the angular distance between those stations appear to be not 60 but 65 seconds, we should be justified in supposing that the additional five seconds were added by the attraction of the mountain, which, drawing the plummets on both sides towards it, increased the divergence upwards of the two vertical lines *a b* and *c d*. But when we know the inclination of the plummet to the true vertical line which passes througth the centre of the sphere, we know the proportions of the two forces acting on it, horizontal and vertical. The one proceeds from the mountain, of which we can estimate the volume, specific density, and distance, the other from the earth, of which we know the size and distance, and learn the specific density by this comparison. Of this nature were the experiments made in 1742 at Schehallien in Perthshire, where the deviations of the plummets on both sides amounted to 11·66 seconds.

But again, the earth's power of attraction may be compared with that of any body of perfectly known size and density. Suppose a slender beam suspended by a fine wire and bearing small balls of metal at its extremities (fig. 28). These, if the beam be set in motion, will oscillate unaffected by gravitation, their rate of movement depending on the length and elasticity of the wire. But if near the path of this movement there be placed two large iron balls, one near each end of the beam, the oscillation will be found to be much accelerated, the small balls receiving an impulse from the greater, as the pendulum does from the earth. Here we know the volume, specific density, and distance of the attracting mass; and by comparing its action with that of the earth on the pendulum, we are able from the earth's size to calculate its specific gravity. The instrument just described, called the Torsion-balance, was employed by Cavendish to determine the weight and density of the earth. Again, in 1843, the same experiment was repeated by Mr. Baily, with additional precautions.

Fig. 28.



As the observed effect of a perfectly calculable addition to the earth's mean attraction may enable us to calculate the specific density belonging to the latter, so a well-ascertained diminution may serve the same purpose. When we descend below the surface of the earth, the portion that remains above us counteracts instead of contributing to the effect of central attraction. When, therefore, we ascertain the effect of the counteracting stratum, with its thickness or proportion to the whole earth and its specific density, by examination of the rocks, we have the means of calculating the specific density of the earth. This method was put in practice by Mr. Airy in 1853 at the Harton Colliery, near Monkwearmouth, Durham. He observed the oscillation of pendulums at the surface and at the depth of 1256 feet below it, and spared no pains to learn the configuration of the ground and the nature of its rocks. These various attempts to determine the mean density of the earth have yielded the following results:—

Maskelyne (on Schehallien)	4·713
Carlini (on Mount Cenis)	4·950
Cavendish (torsion-balance)	5·448
Baily (torsion-balance)	5·567
Reich (torsion-balance)	5·438
Col. James (from attraction of Arthur's Seat)	5·316
Airy (Harton Colliery)	6·565

Omitting the last result, which does not pretend to give the specific density of the earth at its surface, and also the first two, as found by a mode of proceeding not admitting of extreme accuracy, the mean result will be 5·66. The density of the earth's centre is probably about 11.

CHAPTER IV.

The Earth assumed to be a Perfect Sphere.—Positions on it how determined.—The Pole and Equator.—Latitude and Longitude.—The Zenith and Horizon.—Altitude and Azimuth.—The Representation of the Earth.—Insufficiency of the Artificial Globe.—Maps—modes of projecting.—Orthographic Projection.—Stereographic.—Development of a Cone.—Flamsteed's Projection.—Mercator's Chart—its Peculiarities.

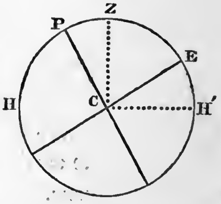
The earth may be assumed to be a perfect sphere, since its deviation from sphericity is so minute as to be undiscoverable without the aid of powerful instruments and refined calculation. We may picture it to ourselves as a globe 7918 miles in diameter, and having a circumference of 24,870 statute miles (of 5280 feet). The mean degree, or 360th part of a great circle on its surface, has a length of 69·15 statute miles; the minute, that is the 60th part of a degree or the geographical mile, measures about 6072 feet, and the second 101 feet.

The fact that equal linear distances measured on the earth correspond exactly with equal angular distances observed in the heavens, proves, as already remarked, that the earth is a globe. If we go northwards towards the terrestrial pole, the pole-star at the same rate approaches our zenith; if we go southwards to the equinoctial line, we there see all the stars rise vertically and describe perfect semicircles round the heavens, while the poles are both visible at opposite points of the horizon.

Thus it appears that the place or geographical position of the observer on the earth may be learned by its reflection, as it were, from the heavens. But as positions in the celestial sphere may be accurately determined by reference to the equator and to great circles drawn to it through the pole, so positions on the earth's surface can be fixed by similar means. The meridians drawn on the globe take the place of the hour-circles in the heavens, and the equinoctial line represents the equator; then the geographical position of any place is accurately determined by the measured arc of the meridian, between that place and the equinoctial line, and by the arc of the latter between its zero or initial point and the same meridian. The former of these, the distance measured on the meridian, is called the latitude, the latter or equatorial arc, the longitude of the place. And here it must be remarked that though the same process serves to determine points in the heavens and on the earth, its results in these two cases are described in different terms. Latitude and Longitude in geography correspond to Declination and Right Ascension in astronomy, which applies the former terms to arcs respectively measured on and perpendicular to the ecliptic. The zero-point of the reckoning in longitude may be arbitrarily fixed at the intersection with the equator of any selected meridian; but the most convenient meridian for this purpose is that which passes through an observatory, and which serves as a basis for the calculations that appear in Ephemerides and tables for navigation. Hence in Great Britain and a great part of the commercial world, the meridian of Greenwich is assumed as the zero- (not the first) point of longitude, which may be read eastward 180 degrees and westward to the same extent, or 360° continuously round by east.

In order to assign to any point on the earth's surface its true place on the meridian, it is only necessary to observe the distance between its zenith and the pole, or what is called its zenith distance. This, since the pole is 90° from the equator, is the complement of the latitude. Thus, if the zenith distance P Z (fig. 29) be 38°, the latitude E Z will be 52°. But again there are 90°, Z H, between the zenith and the horizon. Consequently the zenith distance is the complement of the altitude of the pole P H, or its height above the horizon. The altitude of the pole P H, therefore, is always equal to the latitude of the place Z E. The altitude of the equator, E H, or its height above the horizon, is equal to the zenith distance P Z, and therefore would serve as well as the latter for obtaining the latitude, if it could be easily and correctly observed; but observations on the horizon are on many accounts objectionable, and the equator is but an ideal line drawn through the stars and not directly observable. Yet observations on the horizon are in practice very important, and therefore very frequent. Thus the seaman observes with his sextant the meri-

Fig. 29.



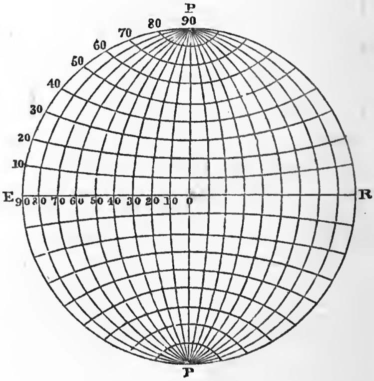
dian altitude of the sun, or its height above the horizon; and from the 'Nautical Almanack' he learns the sun's declination or distance from the equator at the same instant; then by subtracting the declination from, or adding it to, the altitude, according as he is or is not on the same side of the equator as the sun, he finds the altitude of the equator, which being subtracted from 90° gives him his latitude.

The longitude of a place is determined by finding the difference of diurnal time between it and the initial meridian. The earth rotates at the uniform rate of about 15 degrees in an hour, or one degree in four minutes. When it is noon, therefore, on the meridian of Greenwich it is only 11 o'clock at any point 15 degrees further west, while it is 1 o'clock at the same distance to the east. To find the difference of longitude between two places, is the same problem as to determine what time elapses between their noons, or how much time the sun takes in passing from the meridian of the one to that of the other. Now if those phenomena of the heavens which are seen at the same instant from all parts of the earth where they are visible, such as the occultations of Jupiter's satellites, be calculated and announced beforehand, with a statement of the exact times of their occurrence, their continuance and various phases on the meridian of Greenwich, they furnish the means of finding the difference of time between that and other meridians. The observer notes the time intervening between his noon and the occurrence of the phenomenon, and comparing that with the time assigned in the 'Nautical Almanack' for its occurrence at Greenwich, he learns the difference of time between the two meridians; and this difference, changed into geographical distance at the rate of a degree to four minutes, is the required longitude. The correctness of the results thus obtained will depend of course on the regular going of the observer's watch or chronometer. The methods of determining longitude as well as latitude are various; but here it will be sufficient to have explained their leading principles and simplest means.

Being thus enabled to determine, by means of reference to the celestial sphere, the exact positions or places on the earth, we have no difficulty in representing it on a globe with all its natural and acquired features, its lands and seas, its rivers, towns

&c., each in its proper place. For this purpose two points, P P′, exactly opposite to each other on the globe, must be selected for its poles or the extremities of its axis, and halfway between these must be drawn the great circle that divides the globe into a northern and southern hemisphere. This, the terrestrial equator or equinoctial line, marking a plane perpendicular to the earth's axis, divided into 360 equal parts or degrees, is intersected at equal distances, say every ten degrees, by great circles drawn through the poles. These circles are meridians, one of which being selected for the initial or zero, improperly called prime, meridian, they are numbered accordingly 0, 10, 20, &c. from W. to E. continuously up to 360°, or both eastward and westward up to 180° (fig. 30). These representative meridians serve the purpose of facilitating reference to the numeration on the equator, and of exemplifying their use, but have no exclusive right to their titles; for a meridian may be drawn through any point on the earth's surface, and may cut the degree on the equator into any fractional parts.

Fig. 30.



The initial meridian is divided in like manner, the quadrant or fourth part of the circle from the equator to the pole containing 90 degrees, which are numbered from the equator, this being the initial point or 0°, while 90° reaches the pole. At every tenth degree a circle, drawn parallel to the equator and therefore perpendicular to the axis of the globe, cuts the meridians equally. These are called parallels of latitude, and are not great circles of the globe, since they do not pass through its centre. In fact they diminish towards the pole, the radius of each such circle being equal to the cosine of its latitude. Nor are the functions of circles of latitude any more than those of meridians, confined to the few representatives of the class marked on the globe, since a circle of latitude may be drawn through any point, and its distance from the equator may contain any fraction of a degree.

The surface of the globe being divided by lines drawn at equal distances in the planes passing through the axis (the meridians), and by others in planes perpendicular to the axis (circles of latitude), it only remains to delineate on it the details furnished by surveys of different countries, the longitude of each place as found on the equator, reckoning from the initial meridian, and its latitude, reckoned on the meridian drawn through the point thus found, determining its position. The delineation thus made, if founded on good and sufficient observations, may be considered as an image of the earth reflected in some degree from the heavens.

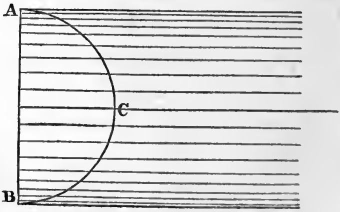
The artificial globe is usually fixed so as to rotate on its axis, in a circle called the general meridian, which is placed vertically in another circle representing the rational horizon, and lies in a plane that passes through the centre of the globe. The sensible or terrestrial horizon (*ὁρίζων*, *bounding*) is the circle which bounds our view on the earth's surface, the sensible horizons of different places therefore pass through different points. But with respect to the stars, the earth being reduced by distance to a mere point, the celestial or rational horizon may be considered as passing always through the same point or its centre. The great circles drawn through the zenith, and therefore perpendicular to the horizon, are called verticals; and by reference to these the positions of objects in the heavens may often be conveniently determined; they stand in the same relation to the horizon as the meridians to the equator. The measured arc of the horizon, reckoned from the north or south point of the horizon, is called the azimuth, and that on the vertical, reckoned from the horizon to the zenith, is the altitude. Azimuth and altitude can always be converted into longitude and latitude when the observer's geographical position is known. The ecliptic is absurdly marked on the artificial terrestrial globe, with which it has no connexion. It does not revolve with the globe, but belongs wholly to the celestial sphere.

The instruments of observation required for geographical observation are now made so perfect and so portable, the value of such observations is so generally understood, and the opportunities of making them so many, that it is a matter of wonder how rare they still are in the latter half of the nineteenth century, and how few pages of a scientific character are to be found in a dozen volumes of travel. How much may be done by an accomplished traveller who knows how to use instruments and how to take care of them, may be learned from the 'Géodésie d'Haute Ethiopíe' of M. Antoine d'Abbadie, a work unique in the very ample literature of travel.

A globe, however perfectly it may represent the whole earth, must be unsatisfactory as regards particular countries. It does not place them conveniently before the eye, nor does it admit of a scale so magnified as to show minute details. Hence it is desirable to transfer the delineation from the globe to a sheet of paper so as to construct a map. But here comes a serious difficulty. The surface of a globe is not a plane, nor convertible into a plane; and the delineation on it cannot be transferred to a plane without great and unequal changes in its proportions. Since the spherical surface, then, cannot be copied faithfully on a plane, it must be copied according to some system, simple and invariable, so that the errors or distortions attending the transfer of figure from the globe to the plane may be fully understood. The globe is generally represented by what are called projections, or representations of it, such as it would be seen from certain conceivable points of view. The projections chiefly employed for planispheres or hemispheres reduced to a plane, are the orthographic and stereographic.

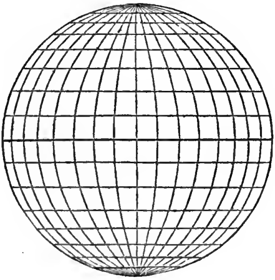
The orthographic projection (ὀρθὸς, *perpendicular*) represents the sphere as it would be seen from a point infinitely distant. The lines projecting it, therefore (fig. 31), are all perpendicular to AB, the plane of projection, and give a perpendicular view of it, optically true, and of course only partially complete; for while the part (at C) that meets the line of vision at right angles is seen in its full proportions,

Fig. 31.



all the rest is foreshortened more or less in proportion to its obliquity (fig. 32). In short this method of projection gives a representation of the globe, rather pictorial than geographical, and is little used, except for maps of the Moon, which always turns towards us one face and is known only from its appearance.

Fig. 32.



In the stereographic projection (στερεὸς, *solid*) the eye is supposed to be placed at a point on the sphere exactly opposite to the point where it is touched by the plane of projection (fig. 33). In this case the lateral parts (of the semicircle A C B), though seen obliquely, are not contracted, but, on the contrary, enlarged, so that the contraction takes place in the middle of the map (fig. 34). But this inequality of scale is not so excessive as to counterbalance the other merits of the stereographic projection, which is generally preferred for maps of the hemispheres.

Fig. 33.

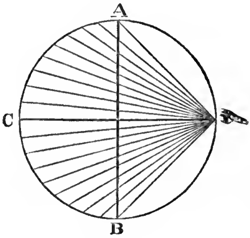
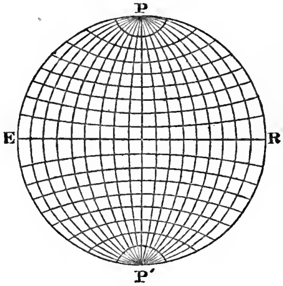
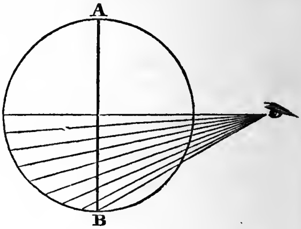


Fig. 34.



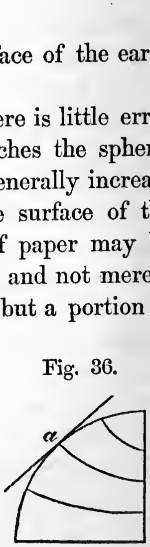
Since the orthographic projection contracts while the stereographic enlarges the marginal portions of the field of view, it was natural that attempts should be made to mediate between them and to place the eye not in contact with the sphere nor infinitely distant from it, but at some intermediate point. If the eye instead of being placed close to the sphere, views it from a distance equal to the sine of 45°, or about seven twentieths of the diameter, the lines drawn to it from the concavity of the sphere will divide the plane of projection into parts very nearly equal (fig. 35). This is the merit of the Globular projection. But the same plane may be at once cut into equal parts by the Equidistant projection. These various modifications, however, do not remove error, but only aim at its concealment or specious distribution. The mode of drawing them may be learned from any treatise on Chartography. Here we have no concern with them but to point out that they do not enable us to represent the surface of the earth collectively in its true figure and proportions.

Fig 35.



It is evident that in any kind of projection there is little error at the point where the plane of projection touches the sphere. The change of scale and distortion of figure generally increase with the distance from that point, and as the surface of the sphere recedes from the plane. But a sheet of paper may be placed on a globe so as to touch it along a line, and not merely at a point (fig. 36). It then forms not a plane but a portion of a conical cylinder, which may be afterwards unfolded or spread out into a plane, so that if the projection be made on the interior or concave conical surface at *a*, it will afterwards form a map, the faultless part of which is not confined to a point, but runs along an entire line of the enwrapping paper. The development of a Cone, as this is called, is the kind of projection generally employed in representing portions of the earth's surface.

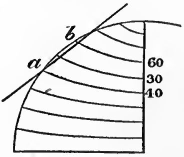
Fig. 36.



In order to derive from this system of development all the advantage belonging to it, the limits of the map remote from the line of projection ought to be collectively at the least possible distance from it, that is to say, they ought to be equally distant from it; the line, therefore, that marks the contact of the cone with the sphere, ought in general to run along the middle of the map. But the peculiar nature and purposes of the map must be in all cases considered; accuracy may be more desirable in one part of it than another. If the northern half of the map were all land and the southern half sea, then the line of projection ought to run through the middle of the northern half; over the sea where no points are marked, there can be no accumulation of error.

By the development of a cone, the changeful scale and distortion of maps is kept within some bounds in one direction—that in which the cone and sphere are in contact; but in the transverse direction error increases rapidly with the distance. Where the region, therefore, to be mapped has great breadth, it has been found expedient to make two lines of contact (fig 37), by supposing the cone not merely to touch the sphere, but to cut through it at *b* and *c*, so that the distance everywhere between the spherical surface on the one hand, and the concave face of the cone on the other, may be the least possible. This end is generally attained by making the three intervals, viz. those between the northern and southern limits of the map and the lines of contact, and that between the latter tolerably equal. Thus in the Map of Europe which extends between latitudes 35° and 75°, the parallels selected for the passage of the conical through the spherical surface are the 45th and 65th. In that of Asia, stretching from lat. 5° to lat. 80°, the selected parallels are the 25th and 60th. Africa extends nearly to the same distance on both sides of the equator; and the plane bent along this circle takes the form, not of a cone, but of a cylinder. Hence, in the maps of that quarter of the globe, the parallels of latitude are straight lines, whereas in those of Europe and Asia they are portions of ellipses.

Fig. 37.



If we draw meridians approaching each other towards the pole, as they do in reality on the globe, and then draw parallels cutting them at right angles (fig. 38), we may construct a map in some respects tolerably correct for a few degrees; but as neither the meridians nor parallels are straight lines, curvature and distortion, with continual change of bearings, increase in it from the centre to the margin. If the

Fig. 38.

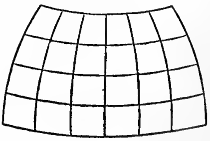
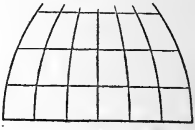


Fig. 39.



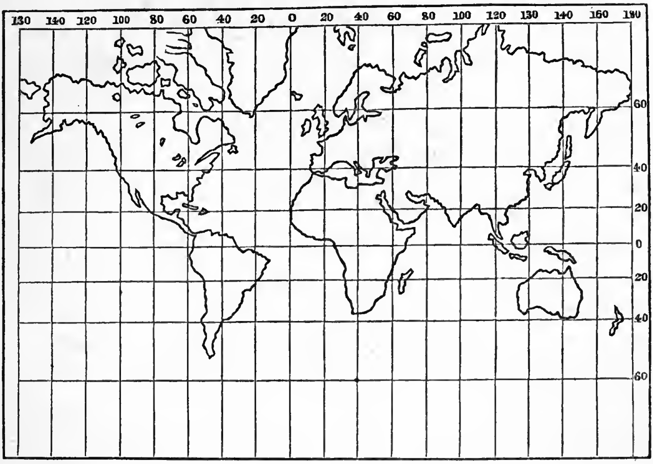
parallels be straight lines (fig. 39), we shall then have Flamsteed's projection, eligible in but a few cases, yet revived not many years ago by M. Babinet, under the title of the Homologous projection, and claiming the advantage of preserving unchanged the true areas of countries. But this pretended advantage is merely theoretical. In practice the exact areas cannot be preserved unless faithfully copied; and where figures must be distorted, fidelity cannot be expected in the copy. Geography gains nothing by sacrificing figure to area. Flamsteed knew the defects of his projection, and never dreamt of its universal use.

One of the most useful projections is that which bears the name of its inventor, Mercator (the Latin for Kaufmann or Merchant); and it is also that which exhibits in its fullest light the difference between plane and spherical surface. When a seaman would sail directly to any distant point, he can steer his course only by reference to the pole or the meridians; but if, persisting in one direction, he always cuts these at the same angle, then his course or Loxodromic line, as it is called, cannot be a straight line, but becomes a spiral; and as the simply direct course becomes on a globe a curve constantly changing its direction, it is a difficult problem in all cases except in sailing due north or south, or along the equator, to find the course which will lead directly to a distant point. But this difficulty is got rid of in charts in which the meridians as well as the parallels of latitude are all straight lines, and in which the chief object sought and attained is to show every thing in its true direction. To this preservation of bearing or direction is necessarily sacrificed the considerations of relative magnitude and of uniformity of scale, which to the navigator are of no importance.

Since the meridians in Mercator's chart are all parallel straight lines, the arcs of parallels intercepted by them must be equal also (fig. 40). But in reality those arcs of parallels with the degrees of longitude measured on them diminish from the equator to the pole in the ratio of the cosine of latitude to radius, or of radius to the secants of latitude. By remaining constant in

Mercator's chart they are magnified inversely in that ratio.

Fig. 40.



Consequently the degrees of latitude are made to increase in like manner in the chart, so as to be proportional to the secants of latitude. Thus all is magnified as it recedes from the equator; but since size and distance increase in the same ratio, the angular distances or bearings of the several points (to seamen the most important consideration) remain unchanged. The law of increase of the degrees of latitude in the chart, namely, as the secant of latitude, renders it impossible to extend the projection to the pole, since the secant of 90° is infinite. The meridians, being parallel, can never meet at the pole. Convenience usually limits Mercator's chart to 75° lat. north and south, which is enough for commerce and navigation.

For the student of physical geography, Mercator's projection has the advantage of exhibiting at once the whole earth with the true bearings and directions of all parts perfectly preserved. This, in considering the course of winds and currents, is very important. But it is necessary to guard against the error of measuring the prevalence of natural phenomena (of the east or west wind for example) by the extent they seem to occupy on the map. Mercator's chart, when confined within the limits of

75 lat., still doubles the earth's surface, all being magnified in proportion to its distance from the equator. Let it be constantly remembered that the middle zone of 60 degrees, from 30° north to 30° south of the equinoctial line, embraces one half of the surface of the globe, the remaining 120 degrees towards the poles forming the other half. The degree of longitude or distance between any two meridians is in lat. 60°, exactly half of that which separates them at the equator. As an extent of at least 30 degrees of latitude round the poles remains utterly unknown, and probably is but icy sea or desolate waste, it may be safely stated that the region between the tropics, 47 degrees in breadth, forms one half of the habitable globe.

From the Table giving the lengths of degrees of longitude and latitude (see p. 44), it will be seen that the degree on the meridian (or of latitude) at the pole exceeds that at the equator by 3845 feet, and the degree of longitude on the equator by 1304 feet. But the inequality of degrees, of which these are extreme examples, is never attended to in maps. It ought, however, to be always remembered that degrees and all the measures derived from them, including nautical and geographical miles, are strictly angular measures, the linear values of which are variable within narrow limits.

CHAPTER V.

The Globe, its Constituents—Solid, Fluid and Gaseous.—Heat the Prime Mover of Circulation.—Dilatation by Heat.—Specific Weight thus changed.—Dilatation, a Measure of Heat.—The Thermometer—Leslie's Differential.—Temperature.—Quantity of Heat.—Specific Heat.—Effects of Contraction.—Convection of Heat.—Conduction.—Reflection.—Diathermancy.—Radiation between Bodies.

Of the sixty-three elements known to chemists, not above a dozen enter into the composition of organized bodies. Some of these ingredients are accidental and non-essential, and all but four appear in very minute quantity. These four, the necessary materials of all that lives, are carbon, nitrogen, oxygen, and hydrogen. The woody fibre of plants is formed of carbon, all drawn from the earth, wherein it exists in enormous quantity, or from the air. The tissue of animal bodies is formed of nitrogen, the preponderating ingredient of the atmosphere. No organized body generates any new substances; it only imbides inorganic elements, decomposes and recombines them. When its period of life expires, those elements are set free; the carbon falls to the ground; the gases return to the atmosphere. Thus a constant circulation exists between animate and inanimate nature. Vegetation takes its nutriment from unorganized matter, the minerals of the earth. Animals subsist entirely on organized matter, ultimately, it may be said, on vegetable food; for herbivorous animals form the support of all the rest. Without them there could be no animal life. Water forms a very large part of all organized structure. It carries to plants their aliment in a state of solution, and by means of capillary attraction circulates throughout them. In the human body it exceeds in the proportion of 4 to 3 the weight of all the solid parts. Thus it will be found that every thing necessary for organization and life exists in the greatest abundance on the surface of the earth and in the atmosphere.

Our globe consists of land, sea, and surrounding air or atmosphere, or, in other words, of solid ground, formed by the aggregation of various minerals ; of water, which, lying on the heavier mineral foundations, fills the hollows of the surface ; and of air, which, being lightest, floats uppermost and envelopes all the rest. The solid part of the earth, as far down as our acquaintance with it reaches, about 15 or 16 miles, appears to be for the most part an oxidized crust—that is to say, it consists of rocks formed by the union of oxygen with various earthy and metallic bases. Water, again, is the protoxide of hydrogen, or oxygen and hydrogen chemically combined, while the atmosphere is a mixture of oxygen and nitrogen. Oxygen, the most active chemical agent, forms more than a third part, perhaps nearly half in weight of the superficial portion of the terraqueous globe, the atmosphere of which is diluted oxygen gas. Thus it appears that the constituent elements, solid, fluid and gaseous, of the earth, as far as it is known to us, are not only akin, but complementary and necessary to each other, the fluid and gaseous portions requiring the support and concentrating power of the solid part, which would itself be wholly unproductive without the other two. Life in every form requires air. Without humidity the earth would be a barren waste ; while the gentle diffusion of water over the land would be impossible, were not the atmosphere capable of being made the means of transporting it.

The prime mover of that circulation which brings into active cooperation the solid, liquid, and aeriform constituents of the globe, is heat, the nature of which is still imperfectly understood ; but its great importance as a physical agent in conjunction with gravitation requires that its modes of manifestation should be carefully studied. It is believed that heat consists in a peculiar vibration directly affecting the atomic constitution of bodies ; but as it is difficult to find clear expression for obscure conceptions, we shall here prefer to adopt the language in common use, and speak of it as an imponderable something that enters into or quits bodies in greater or less quantity, or may abide in them as a constituent element. This language is merely figurative, and does not assert the materiality of heat, but only tacitly assumes it.

Under the influence of heat the atoms of a solid body lose more or less of their coherence. At first the heated body expands; but if the heat be continued, the atoms of the body separate and move independent of each other, so that the solid becomes a fluid. With still more heat the particles repel each other, and the fluid takes the gaseous form. In effecting these changes heat is expended, and is represented in hypothetical language as having become a latent constituent of the fluid or gas. In short the state of matter, as solid, fluid, or gaseous, often depends on the extent to which it has undergone the action of heat.

The expansion or dilatation of bodies by heat is a very important as well as interesting phenomenon. In the case of solids, the expansion, being relatively small, may be most conveniently observed in the increasing length of slender bars; and experiment shows that by 180 degrees of heat (Fahrenheit's scale), from the freezing- to the boiling-point (32°–212° F; 0–100° C.) bars of different materials are elongated as follows:—

Zinc increases by one part in	323
Lead	351
Tin	516
Silver	524
Copper	581
Gold	682
Iron wire	812
Platinum	1167
Flint glass	1248
Fir wood	2451
Black marble	2833

The insensibility of Lucullite or black marble to ordinary changes of temperature, a character which, to some extent, it bears in common with all earthy minerals, once recommended it to the Royal Society of Edinburgh as the best material for the pendulum of a clock. The increase in bulk, or all three dimensions caused by heat, may be assumed, when the dimensions are small, to be about three times that in length. Thus glass expands with the heat above specified, one part in 416. Of all solid bodies ice is the most expansible, a bar of it lengthening with heat at a rate which, for 180 degrees, would add to it a 267th part.

Liquids expand much more rapidly. Thus, with a rise of temperature from 32° to 212° Fahr. (0–100° C),—

Alcohol, or spirits of wine, increases in volume one part in	9
Fixed oils	12
Water	23
Mercury	55½

All gases expand alike, so as with 180 degrees of heat (from the freezing- to the boiling-point) to increase in volume $\frac{11}{30}$ or about $\frac{1}{490}$ for 1 °Fahr. Such, therefore, is the expansion of atmospheric air. But vapour, which is not a true gas, dilates to the extent of only $\frac{10}{30}$ for 180°, or about $\frac{1}{540}$ for 1° Fahr., and continually less with increasing temperature. All bodies that expand with heat, return on cooling to their original dimensions. Dilatation by heat, therefore, implies contraction by cold.

The dilatation or contraction in question, however, is not perfectly uniform at all temperatures. Water, instead of contracting, dilates as it cools down from 39°·34 to 32°, and within these limits contracts with increase of temperature. The indicated temperature, therefore, 39°·34, is that of the greatest density of water. Some metallic alloys also when melted dilate in cooling, and thus form exceptions to the general law. But these exceptions are all connected with, and are preliminary to, or follow upon, change of state (from solid to fluid, from fluid to gaseous, and *vice versâ*); and accordingly the law of dilatation holds good in strictness only with respect to temperatures remote from such change. The effects of heat on the more susceptible kinds of matter may be thus briefly exhibited :—

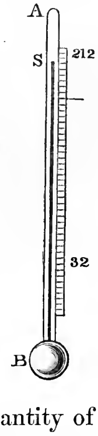
By the addition of 180° F. (from 32° to 212°) or 100 C,

1000	parts of	iron	become	1004	parts.
1000	„	water	„	1044	„
1000	„	vapour	„	1342	„
1000	„	air	„	1366	„

It is obvious that as bodies dilate they become superficially lighter. Their volume increases while their weight remains unchanged; and consequently with the same volume they have less weight. In liquids and gases, therefore, every partial change of temperature, as it causes also a partial change of weight, gives rise to an internal circulation or a new adjustment of the variously affected parts. Water, when cooled at the surface, where it is most exposed to change of temperature, contracts, becomes heavier, and sinks till it arrives at a level of like temperature and density. If it be heated below, it dilates, rises, and spreads over the surface. This mode of distributing heat by internal movement is called *convection*. Air, in like manner, when heated from the ground, goes off in an ascending current; and being extremely mobile as well as dilatable, the slightest change of temperature sets it in motion. Consequently, since heat is unequally distributed over the globe, varying from place to place and from hour to hour, it keeps the atmosphere in perpetual motion, the circulation caused by it being briskest near the ground.

The dilatation caused by heat, being within certain limits uniform, may also serve for its measure, on the presumption that so much dilatation indicates so much heat. Suppose, therefore, a glass tube (fig. 41), open at one end, A, and with a bulb, B, at the other, to be nearly filled with mercury, and then set over a lamp till the mercury boils, so that the air may be expelled. The tube being now quickly and perfectly closed and removed from the lamp, the mercurial column will contract as it cools, and therefore sink, leaving a vacuum above it; and as it sinks its upper surface will successively indicate every gradation of temperature, from that of boiling mercury to that of the surrounding air, which may be cooled down to or below the freezing-point. The instrument thus made is the ordinary mercurial thermometer. It is obvious that, since mercury dilates about $\frac{1}{9990}$ part for every degree Fahr. of added heat, care must be taken to adapt the capacity of the tube to the quantity of the mercury, and to the extent of the scale or the temperatures ot be measured. In order that the degrees, themselves equal, may

Fig. 41.



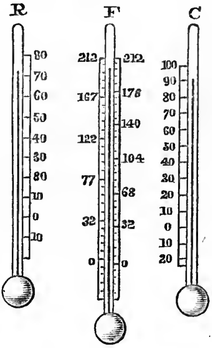
mark equal dilatations, the tube ought to be of perfectly uniform capacity ; or if unequal, then the marked degrees ought to vary in length inversely as the capacity of the tube. To complete the instrument, it only remains to affix to it a convenient scale, limited by temperatures perfectly ascertained and constant in nature, so that different thermometers may, as it were, speak the same language and admit of being compared.

For the range of temperature to which meteorological observations are usually confined, the thermometer just described is entitled to preference, since mercury, becoming fluid at −40° (72° below the freezing-point of water) and boiling at 662° F. (350° C.), dilates with regularity throughout this wide range, except only near its extremes. In no part of the earth does temperature approach the latter limit. Within the polar circle, and at some points without it in Eastern Asia, the cold of winter falls for a month or more below that of frozen mercury. In such a case recourse must be had to the spirit-thermometer, filled with alcohol or spirits of wine, which it has been hitherto found impossible to congeal, the greatest artificial cold only making it thick like oil. In the polar regions, therefore, the spirit-thermometer is indispensable ; but its indications cease to be trustworthy at moderately high temperatures, and at 172° Fahr. the spirit boils.

The thermometers first made, and which, under the name of Florentine tubes, remained in use till the end of the 17th century, were all spirit-thermometers. Some of them had a scale of 100 parts, 20° corresponding to the temperature of ice, and 100° to the greatest summer heat. More frequently the scale was divided into 50 parts, 13° and 40° being respectively adjusted to the temperatures just mentioned. These old thermometers appear to have ranged from 3° to 131° of Fahrenheit's scale. Réaumur found that strong spirits, which, when cooled by ice, formed 1000 parts, dilated to 1080 parts at the temperature of boiling water. He therefore adopted the scale which now bears his name, and divided the range from the freezing- to the boiling-point into 80 degrees. De l'Isle was the first who made the temperature of boiling water a fixed point in the themometric scale, his other fixed point being the temperature known to be constant in the cellars of the Observatory in Paris (55° F.). The adoption of the temperature of melting ice as a standard point, a most important improvement, was due to Sir Isaac Newton. This is commonly but erroneously called the freezing-point. Congelation ordinarily takes place a little below that point, and may be much retarded. But the temperature of melting ice or of ice and water mixed is perfectly constant. Fahrenheit took for the zero of his scale the artificial cold of ice melted by common salt (32° below the freezing-point), which he believed to be the lowest observable temperature. This arbitrary zero now disfigures his scale. Without it the division of the thermal interval between the temperatures of the congelation and the ebullition of water into 180° would be most convenient, and easily comparable with the scales of Réaumur and Celsius. The last-named philosopher divided the interval in question into 100 parts; but he reckoned downwards, taking the boiling-point of water for zero. In the modern Centigrade thermometer his scale is adopted, but with inverted numeration, the zero being at the freezing-point.

In comparing, therefore, the three thermometric scales now remaining in use, viz. those of Réaumur, Celsius (the Centigrade), and Fahrenheit (fig. 42), it must be borne in mind that the interval between the fixed points was divided by the first into 80, by the second into 100, and into 180 by the last, who also added 32° below the freezing-point. In reducing, therefore, the Fahrenheit scale to that of Réaumur or Celsius, care must be taken to begin by deducting those 32°. If the reduction be from Réaumur or Celsius to Fahrenheit, they must be finally added. The mutual ratios of the degrees of those scales are as follows:—

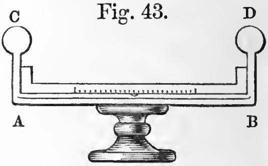
Fig. 42.



Réaumur.	Celsius.	Fahrenheit.
1°	$\frac{4}{5}^\circ$	$\frac{4}{9}^\circ$
$\frac{5}{4}$	1	$\frac{5}{9}$
$\frac{9}{4}$	$\frac{9}{5}$	1

Besides these well-known instruments for measuring temperature, there are two of much greater delicacy to which it may hereafter be necessary to refer. Leslie's differential air-thermometer is formed by joining two equal tubes, C A, D B (fig. 43), terminating above in bulbs, at right angles to another tube, A B, placed horizontally, and containing a small quantity of coloured liquid. So long as the air has the same temperature in both the vertical tubes, the liquid in the horizontal tube will remain unmoved. But if by holding the hand near one of the bulbs the air in it be warmed and thereby caused to dilate, the liquid will be pressed to the other side. A scale may be affixed to the horizontal tube, or to one of its upright branches, to measure the motion of the liquid or of the globule of air at its surface. The thermo-electric multiplier of Melloni is a more complex and still more delicate instrument. It is founded on the principle that when two different metals are in contact, a difference of temperature between them, or, which comes to the same thing, a communication of heat from one to the other, gives rise to an electric current, which, if the metals be connected by wires with a galvanometer, manifests itself by the deflection of a magnetic needle. The metals that form the most energetic thermo-electric couple are bismuth and antimony; and thirty of these couples clasped together form Melloni's thermometric apparatus, the sensitiveness of which detects differences of temperature otherwise imperceptible.

Fig. 43.



The thermometer enables us to ascertain the temperature of bodies, or the heat which they are free to communicate, and which flows off and on between them to preserve the general equilibrium of heat. But it is impossible to measure by mere contact the quantity of heat which underlies in any body its manifestations of temperature. Heat presents itself to our notice under different aspects. Bodies of different kinds differ in susceptibility of heat, and require to be acted on by it in different degrees before they acknowledge its influence. Some bodies, when exposed to heat, show its effects at once by rise of temperature; others subjected to the same trial change but little and very slowly. The latter, naturally compared to vessels which do not quickly show at the surface the liquid poured into them, are said to have a great capacity for heat. Receiving much and showing little they seem to contain heat. The relative amount of this retentiveness in a body is called its specific heat, in respect of which bodies differ widely. A striking example of this is to be found in boiling water and the steam that issues from it. They have the same temperature, yet the steam contains heat enough to raise five times the same quantity of water from the freezing- to the boiling-point. Again, ice and the water it floats in have the same temperature; yet ice, in order to become fluid, must absorb 142° of heat—that is to say, as much heat as would raise 142 times the same weight of water 1°.

The difference between equal temperatures and equal quantities of heat may be rendered evident by very simple experiments. If water at 212°, or boiling heat, be mixed with an equal quantity at 68°, the mixture will have a temperature of 140°, or the arithmetical mean of the two, the whole heat being divided equally between them. Equal quantities of water, therefore, evidently take equal quantities of heat. But with bodies of different kinds the results of such mixture will be different. If a pint of mercury at 100° be mixed with a pint of water at 40°, the temperature of the mixture will be, not 70°, the arithmetical mean, but 60°, the 40° of heat lost by the mercury adding but 20° to the temperature of the water. If the experiments be made with equal weights, it will be seen that the same quantity of heat which would raise the temperature of water 5°, would raise that of mercury 115°, and therefore water requires, for any given rise of temperature, 23 times as much heat as mercury. The great difference existing between bodies of different kinds but equal weight, in relative amount of specific heat, will be seen in the following Table :—

Water	1000	Lime	204	Zinc........	96
Aqueous vapour	847	Alumina	200	Copper ...	95
Ice	513	Glass... ...	198	Tin	56
Gypsum........	272	Felspar ...	192	Antimony	50
Chalk...........	256	Silica	179	Mercury ...	43·5
Wood charcoal	241	Diamond	147	Gold	32
Air..............	237	Iron	113	Lead	31

As the specific heat of a body is the relative quantity of heat required by it for a certain rise of temperature, so its latent heat is that which has been expended on it, not to raise its temperature, but to effect in it a certain change of state, and must be considered not as a constituent element of the body, but as an indispensable expenditure, preliminary to its existence in that state. Thus the specific heat of water (1000) expresses no absolute quantity, but is only a term of comparison which enables us to state in what proportion the heat-absorbing power of water exceeds that of ice (513), or of antimony (50). But the latent heat of water (142°) means the quantity of heat which must have at some time acted on it, in order to bring about its fluidity, and which must be absorbed or consumed by ice in melting. The water thus produced has the temperature of ice; so that the heat expended in the melting has totally disappeared and is said to be latent, though sufficient to raise the temperature of 142 times as much water one degree. In like manner, water at the boiling-point goes off in steam. It rises slowly to that point, and then ceases to increase in temperature though the heat be continued. Ice-cold water may be raised to the boiling point in an hour, but it will take five hours to evaporate it or convert it into steam, which yet has only the temperature of boiling water. What, then, becomes of the heat expended during those five hours? It is said to be latent in the steam; but in truth it has been expended in reducing the water to the gaseous state or changing it into steam. Ice becomes changed into water by the apparent absorption of 142° of heat; and, again, water is converted into steam by the further absorption of 964°. The absorption of heat by the melting ice in the one case, and by the steam in the other, may be regarded as a cooling process, since were the heat not thus consumed, it would have caused increase of temperature in its vicinity. On the other hand, the formation of ice and the condensation of steam or vapour both contribute to warmth; for in these cases latent heat is liberated and helps to moderate the low temperature producing the change.

Most, if not all, solid bodies may be forced by heat into the fluid or gaseous state. Some, as the diamond, pass off at once into gas without ever becoming fluid. Several gases, on the other hand, have been found to be reducible by cold and pressure to the fluid or solid state. Others prove refractory, and defy all attempts to alter their condition. Yet it is thought that they remain exempt from change only because the means of reducing them have not yet been discovered.

Increased temperature causes, as we have seen, the expansion of bodies, diminished temperature their contraction. But if dilatation be suddenly produced in a body by mechanical or chemical means, the heat required for the change is drawn from the sensible heat, and cold is produced. Thus ice may be made under the receiver of an air-pump by rapid evaporation and the dilatation of vapour. Liquefaction without heat by chemical means alone, is followed, when the process is rapid, by intense cold. Ice or snow melted by salt yields water of very low temperature. The like materials, cooled in that water and again mixed, melt at a still lower temperature, and so, by continuing the process, intense cold may be reached. Sulphuric and some other acids dissolve ice more rapidly than common salt. Faraday, employing ether and solid carbonic acid *in vacuo*, arrived at the low temperature of −166° or 198° below the freezing-point. Natterer, substituting for those materials liquid nitrous oxide and bisulphide of carbon, has since reached −220° Fahr.

Compression, on the other hand, generates heat and raises the temperature of the compressed body. Tinder may be lighted by compressing air quickly in a tube to one fifth of its volume. The heat of guns when fired arises chiefly from the percussion; for the combustion of gunpowder, felt but for an instant, can exercise but little heating-power. Iron may be made red-hot by a blow from a heavy hammer. The heat of slaked quicklime is due to the solidification of the water thrown upon it, that of water mixed with sulphuric acid to the contraction of the mixture; for if a glass be filled to the brim with water and sulphuric acid be gently added to it drop by drop, the mixture will not overflow, but will be seen to retire within the glass. Friction, the heat of which is so frequently observable, and so often resorted to for procuring heat and flame, is but a case of compression. Water may be heated by continued and violent disturbance. It is well known to seamen that the sea is warmer in tempestuous than in calm weather. Mr. Rennie succeeded in boiling an egg in water heated by churning.

The temperature of a body is the degree of heat which it is at any time ready to communicate. The diffusion and equalization of temperature among bodies is continually going on, for equality of temperature is enjoined by nature as strictly as the level of water. A body warmer than those about it loses heat, or if colder acquires it, this flux and reflux continuing as long as inequality of temperature exists, and with an energy proportional to the inequality.

The communication of heat between solid bodies is effected, according to circumstances, either by conduction, if they be in contact, or if they be at some distance asunder, by reflection or radiation. Conduction is the transmission of heat from particle to particle, and varies much in different bodies. Dense, compact bodies, and metals in particular, are the best conductors. Water and air are among the worst; and substances of a fibrous or filamentous nature also, such as wool, down, cotton, fur, &c., which hold much air involved in them, refuse to conduct heat. How widely substances may differ in relative conducting-power will be evident from the figures of the following Table, derived from the experiments of MM. Wiedemann and Franz:—

Silver	136	Zinc	25·8	Lead ...	11·5
Copper	100	Tin	19·7	Platinum	11·4
Gold ...	72·5	Iron	16·2	Palladium	8·6
Brass...	32·1	Steel	15·8	Bismuth	2·4

In fluids heat is ordinarily distributed by convection or internal circulation, the warm fluid rising and giving way to a descending cool current, which again rises in its turn. But mercury has some conducting-power, which would be 4·7 in the preceding Table. Fluids may, to a very small extent, be heated from above. Water treated in this way is found to have about a 95th of the conductiveness of copper. That heat is diffused through water almost entirely by convection is easily proved. If two glasses of equal size and similar shape be nearly filled with water and frozen, and then be completely filled up, the one with cold the other with boiling water, it will be seen that the lowest stratum of the hot water is very soon cooled, and effectually cuts off all communication between the warm fluid above and the ice below, so that, at the end of half an hour, the quantity of ice melted is nearly the same in both glasses. In this case, therefore, there has been no appreciable conduction of heat downwards. If in one of the glasses be placed a small roll of cotton-wool, and both be then filled with warm water, that with the wool will cool much more slowly than the other ; and if they be filled with cold water, and then be partially immersed in hot water, the glass with the wool will lag behind in change of temperature. In these cases the wool prevents change of temperature, because by checking circulation it hinders the convection of heat.

The bodies that best conduct heat are those in which extreme temperatures are generally observed. Thus metals are cold to the touch, because they rapidly extract heat from the hand ; but, again, they easily become insupportably hot, communicating heat with unpleasant facility. Wool or cotton, on the other hand, hardly ever manifest a change of temperature. Among the worst conductors are air, water, and the earthy minerals composing the great mass of the globe.

The reflection of heat is governed by the same laws as that of light. When light falls on a smooth or polished surface, capable of reflecting it, a portion of it is equally diffused in all directions, rendering visible the illuminated surface ; while another portion goes off in a direction depending on the relative positions of the light and the surface that receives it. If A B (fig. 44) represents that surface, the incident ray of light, L P, will be reflected in the same plane, so that the angle of reflection, R P B, shall be equal to the angle of incidence, L P A. In like manner M P will be reflected to N, O P to Q. To the eye on the line N P (fig. 45) the reflected light will be seen at P ; but if the eye be removed to N′ or N″ the image will move to P′ or P″, the angles of incidence and reflection being always

Fig. 44.

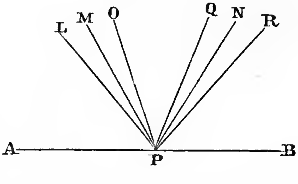
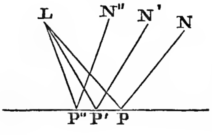


Fig. 45.



equal. Thus the light, though from any one position seen at a single point, is in truth reflected from every part of the surface, as the observer may easily prove by change of place. The proportion of the reflected to the radiated or diffused light, and the contrast between them in respect of luminosity, depends altogether on the angle of incidence and the nature of the surface on which the light falls.

In like manner and in similar conditions heat also is partly reflected, partly radiated. Hence the rays of heat from a sunbeam, for example, may be collected in a focus of a concave mirror (fig. 46); and if a hot body (H, fig. 47) be placed in the principal focus of such a mirror, its heat thence reflected to the surface of another concave mirror placed opposite to the first, will be collected in its focus (F), so as to ignite gunpowder or to exhibit any other effect of heat at a considerable distance from its source by means of reflection.

Fig. 46.

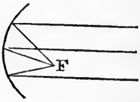


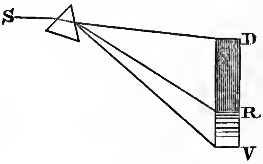
Fig. 47.

Intense heat has been obtained by a combination of many concave mirrors, all reflecting the sun's rays into a common focus. If, instead of using a lamp, a ball of red-hot iron or a vessel filled with hot water, we make the experiment with a piece of ice, the communication of temperature will be similar to that described, and the coldness of ice will be felt in the focus of the second mirror. And here it is as well to observe, that cold means only a low degree of heat. In ordinary language we call that hot which, exceeding the temperature of the hand, communicates heat to it; and that we call cold which abstracts heat from the hand that touches it. But heat and cold are only the opposite extremes of one thing, differing merely in degree and in the sensations produced by them. Since heat is best reflected by polished surfaces, and the more of it reflected the less radiated or absorbed, smooth or polished surfaces conduce to internal coolness. Of the difference between bodies in their power of reflecting heat the following examples will suffice :—

Reflecting Power.

Copper	100	Tin	80	Lead	60
Silver	90	Steel	70	Glass	10

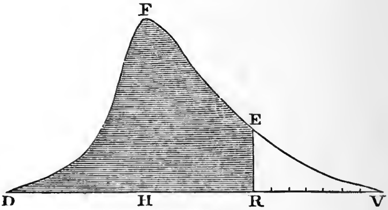
Fig. 48.



Heat may also be refracted or bent from its course in the same manner as light. Captain Scoresby, the celebrated Arctic voyager, surprised and delighted his seamen by showing them how to light their pipes from the sun's rays by means of a lens of ice. It was discovered by Sir William Herschel that in the solar spectrum formed by a glass prism (fig. 48), there is little heat at the violet or most refracted end (V), but that it increases towards the red or least refracted part (R), and continues, still increasing, beyond the luminous spectrum. Hence it is evident that rays of light and heat, though mixed together in the sunbeams, are not identical. Herschel's experiments were made with a prism of glass, which absorbs or intercepts dark heat and therefore led only to incomplete results. Heat, like light, is transmitted through bodies more or less transparent; but it is not all equally transmissible. In general the power of heat to penetrate different substances increases with the intensity of its source. Dark or non-luminous heat, as that from a vessel of boiling water, has little or no penetrating power. Rays of heat from a lamp, though not wholly without that power, will be completely stopped by the transparent screen which gives passage to rays of the same temperature from a distant furnace. The heat of the sun passes with little loss through a glass screen which totally intercepts the heat of a brisk fire at a little distance. Bodies also differ widely in diathermancy, or the power of transmitting heat. A few imperfectly transparent bodies, as opal, transmit heat in larger proportion than others which are perfectly transparent. Smoky topaz gives passage to five times as much heat as water. The most perfectly diathermanous substance known is rock-salt, which allow passage to more than 92 per cent. of solar heat.

When the solar spectrum formed by a prism of rock-salt is closely examined, it is found that the dark heat refracted much exceeds the luminous heat in extent, and still more in intensity. In fig. 49 R V represents the luminous spectrum, R D the non-luminous refracted heat; the line V E F D shows the intensity of the heat, increasing from V (violet) to R (red), and attaining its maximum at H. Light and heat, allied by nature, come to us blended together in the sunbeams, but in very unequal quantities, the dark or invisible heat being not less than $\frac{7}{8}$ of the whole. This is quickly seized on by the vapour in the atmosphere, which detains all but the penetrating luminous rays. Snow and ice are diathermanous to luminous heat; and therefore bright sunshine has less effect in melting snow than dark heat. If a piece of ice be exposed at once to the rays of an Argand lamp and to the radiation of heated copper, both being so placed as to exert like power on the position of the ice, it will be seen that the copper melts it much more rapidly than the lamp. The effect of radiated heat on snow is easily observed. The snow melts most quickly about stones, or sticks or fallen leaves. This is most strikingly exhibited at great elevations, where the air, clear and dry, having itself little heat, lends no aid to the sun's rays. On the snows of the Alps the superior melting power of radiating or dark heat is conspicuous. The snow melts rapidly about every stone or withered leaf, while the sun's direct rays seem to produce on it no effect.

Fig. 49.



If two bodies at unequal temperatures be placed at some distance apart, the warmer of the two will gradually cool, while the colder will grow warm, the heat continuing to flow from the former to the latter till their temperatures become equal. In this case the heat darted through space in straight lines and in all directions, in the same manner as light, and, unaffected by the interposed medium, is said to be radiated. The activity of radiation is in general proportional to the difference of temperature between the radiating body and the surrounding medium. It is favoured also by the ampleness and roughness of the radiating surface, and by circumstances of superficial texture, often but not regularly connected with darkness of colour. Since radiation takes place only from surface, the more ample the surface the greater the facility of radiation. Rough surfaces radiate more freely than polished, because roughness consists in minute irregularities that multiply surface. But independently of their visible, superficial characters, bodies differ much in the power of radiating heat, as will appear from the following examples :—

Relative Power of Radiation.

Water	100	Indian ink	80
Lampblack	100	Mercury	20
Crown glass	90	Bright iron	15

The importance of the fact that luminous heat from an intense source has the power of piercing through space unabsorbed and undiminished, but loses that power on becoming radiated and obscure heat, will be manifest further on, when we come to consider the action of the solar rays shooting through the atmosphere from above and heating it from below.

CHAPTER VI.

Sources of Heat—internal—proved in Wells—Mines.—Shergin's Well.—Heat of Earth now constant.—Star Heat.—The Sun, the chief source.—Effect of Solar Spots.—Conditions of Insolation.—Angle of Incidence.—Loss by Obliquity.—Effect of Sun's Declination.—Distribution of Solar Heat.—Length of the Day.—Penetration of Heat into the Ground.—Line of Constant Temperature.—Effects of Sea and Land.—Ptolemy's Climates.—Heating Power of the Sun.

The heat of the earth's surface may be considered as derived from three sources, viz. :—1, the interior of the globe ; 2, the starry heavens or general space ; and 3, from the sun. It is well ascertained that the sun's rays penetrate but a little way into the ground, not more in middle latitudes than 80 or 90 feet. The heat found lower down, therefore, must come from some other source ; and since this heat increases the deeper we go, we cannot avoid inferring the existence of an internal source of heat. It is true that grottoes and what are called ice-cellars seem to be proofs of subterranean coolness. But these are in fact only pits of no great depth, which, admitting the air with its temperature and being never reached by the sun's rays, while cold air sinks into them, treasure up the winter's cold. They are so circumstanced as to receive little heat either from within or without.

But the numerous warm springs issuing from the ground in all parts of the earth, plainly indicate some internal source of heat. Artesian wells in particular prove the relation existing between temperature and depth. Sunk in different countries and climates, and all agreeing in general results, they cannot be supposed to owe their elevated temperature to merely local and exceptional causes. The water issuing from them may be presumed to have the temperature of the depth at which it is collected ; and as it rises rapidly through narrow openings, it can be but little affected by the external air. In boring the Artesian well of Grenelle in the suburbs of Paris, it was found that, the temperature of the air being 51°·34 Fahr., that of the water at a depth of 94 feet was 53°·6 Fahr.

1309 „ 76°·3
1657 „ 79°·51
1802 „ 82°·4

The weight due to this kind of evidence may be better estimated from the following Table, which shows, with the depth of the well, the average length of descent effecting in each case a rise of temperature of 1° Fahr.

	Depth in feet.	Average descent for 1° Fahr.
Well at Pregny, near Geneva ...	724 ...	59·3 feet.
Schweitzer Zell, Basle	406 ...	52·6
Pitsbuhl, Burg	485 ...	48·2
Kentish Town, London	1100 ...	52·9
Grenelle, Paris	1800 ...	59·6
Mondorf, Luxemburg	2388 ...	57·5
Rudersdorf, near Berlin	935 ...	29·7
Monte Massi, Maremma, Tuscany	1139 ...	27
St. Louis, Missouri	3387 ...	65

The well at St. Louis, still incomplete, is the deepest yet sunk; but the observations made of its temperature are of doubtful accuracy. At Monte Massi the well descends 980 feet below the level of the sea, and has at its bottom a temperature of 107°·6 Fahr., the highest, we believe, yet reached underground; but being situate within or close to a volcanic region, it may be reasonably deemed exceptional. The unaccountable singularity of Rudersdorf also makes it liable to objection. Omitting, therefore, the last three names, we may conclude from the preceding list, that the mean descent below the surface of the ground required to raise the temperature 1° Fahrenheit is, within the short distance to which experience reaches, about 54 feet.

In mines it is difficult to arrive at accurate conclusions with respect to the temperature of the ground, the numerous lights burning, and workmen respiring in them, and the constant admission of air from above, being so many causes of disturbance that cannot be set aside. Satisfactory results can be obtained only by sinking the thermometer in the rock. The results of the most careful experiments of this kind are here exhibited :—

	Depth.	Increase of depth for 1° Fahr.
Monte Massi, Coal-mine, Tuscany	44·6 feet	19·8 feet.
Uralian Mines	81	36
Coal-mine, Buda, Silesia... ...	82	36·4
Monkwearmouth, Newcastle ...	132	58·7
Rosebridge Colliery, Wigan ...	2445	54·3
Astley Pit, Cheshire	2055	76·8
Salt-mine, Bex	167	74·2
Erzgebirge	170	75·5
Carmeaux Coal-mine	175	77.5
Wieliczka, Hungary	209	97
Mean of Prussian Mines... ...	232	103
Copper-mines, Mannsfeld ...	493	219

In the calculations from which the figures of the second column of the preceding Table are derived, it was probably assumed that the increase of temperature downward is uniform. But careful experiments show that in the cooling of spherical masses, the decrease of heat from the centre to the surface becomes much more rapid towards the latter—a conclusion manifestly borne out by the preceding Table, and in perfect accordance with the following results of observations made in the mines of Cornwall and Devonshire :—

Depth.	Mean Temperature.	Rate of Increase of Temp.
50 feet	60°·72	1° for 46·64 feet
130	70·54	„ 70·9
185	74·72	„ 125·57

In these mines the mean temperature at the depth of 100 fathoms, that of the external air being 50°, is 66°·43, at 200 fathoms 77°·03, showing an increase of 1° Fahr. for every 36 and 44·4 feet respectively. Besides the palpable causes of disturbed temperature above enumerated, there are in some mines chemical processes productive of heat continually going on in the minerals and manifested in local irregularity. This is particularly observable in coal-mines. In the mines at Monte Massi, in Tuscany, the increase of temperature downwards appears to be for some distance from the surface nearly 1° Fahr. in 19 feet; while at Carmeaux (Tarn, France), in two galleries little more than a mile asunder, the respective rates of increased temperature are 1° for 52 and 76 feet. In the Cornish mines the heat is invariably greater in the metallic veins than in the surrounding rock, and in the veins of copper than in those of tin; that is to say, it is greater in the better conductor; whence it is manifest that the heat comes from within and not from the air or the surface of the ground. The temperature of deep mines depends not a little on the character and inclination of the overlying strata. Heat passes off more readily in the line of stratification; and consequently the ground cools more rapidly beneath highly inclined strata, and is more affected by the passage of water from above. Hence, in the Astley Pit (Cheshire) the increase of heat downwards is irregular and comparatively slow, while in the Rosebridge Colliery (near Wigan), beneath perfectly horizontal strata, temperature rises for the first 600 feet at an average rate of 1° for 35 feet, and continues to rise steadily, though at a regularly decreasing rate, to the extreme depth reached.

A curious proof of the increase of heat downwards is to be found in the history of an attempt made to dig a well in the frozen soil of eastern Siberia. The river Lena, near Yakutsk, lat. 62° 2′ N., frozen during eight months of the year, overflows its banks soon after the breaking up of the ice, and rushes down in an immense flood excessively turbid and impure. It was in the hope, therefore, of finding pure water at the depth of five fathoms, or the lowest level of the river, about a mile distant, that the Russian merchant, Fedor Shergin, residing in Yakutsk, commenced in 1828 to sink a well. The progress of the work was unexpectedly slow. The workman thought that he had struck upon rock; and some time elapsed before it was clearly understood that the obstacle encountered was the frozen soil. In 1831 the depth of 105 feet had been reached without penetrating through the frozen ground; and the undertaking would have been abandoned had not Admiral von Wrangell, passing through Yakutsk on his way to America, perceived the interest attaching to it, and urged on the Imperial Academy of Sciences at St. Petersburg its further prosecution for the benefit of science. In

1837, when the depth of 382 feet had been reached, still in frozen ground, the well was carefully covered over to exclude the external air, and in 1844 its temperature throughout was examined by Middendorf for the Academy of Sciences. Thermometers inserted in holes bored for them in the sides of the well, gave the temperatures at the depths of 7, 15, 20, 50, and thence at intervals of 50 to 350, and at 380 feet. At 7 feet the temperature was 12° 8′ Fahr., at 380 feet 26° 6′. The general conclusions derived from these observations were, that the ground is perpetually frozen to a depth of about 612 feet, and that the distance which in descending is attended with an increase of temperature of 1° Fahr. is, near the surface ...... 4 feet.
at the depth of 100 feet ... 20½ „
„ 200 „ ... 40 „
„ 300 „ ... 60 „
„ 400 „ ... 78 „

It must not be supposed that the cold of the Siberian winter at the present day, though extremely intense, can freeze the ground to a depth of 600 feet. The frozen soil in the valley of the Lena is a formation of what geologists call the Glacial period, and may be regarded as an aqueous rock protected from change beyond the depth of a few feet by the shortness of the summer and the general rigor of the climate.

If 54 feet be assumed to be the mean distance downwards, corresponding to one degree of increased temperature (and such is the estimate warranted by observations made near the earth's surface), then, supposing the temperature of the surface to be 50°, the heat of boiling water (212° Fahr.) will be found at the depth of 8748 feet, or about a mile and two thirds. But if, instead of 54, we take 100 feet as the average distance downwards required for a rise of temperature of 1° Fahr. (and even this is probably true only for a comparatively moderate distance towards the earth's centre), the temperature in question will be first found at a depth exceeding three miles. But under the increased pressure of three miles at the base of the atmosphere water would certainly not boil at a less temperature than 240° Fahr. We must therefore descend still lower to find boiling water ; and if we suppose the ebullition to take place at the base and under the still greater pressure of a column of water reaching the surface of the earth, we must seek it at a depth exceeding seven miles, where it has a temperature of at least 745° Fahr. The temperature of 2800° F., sufficient on the earth's surface to reduce all metals and rocks to the fluid state, would, under the same conditions, be first met with at the depth of 53 miles. But these calculations need not be implicitly accepted; the increase of temperature at great depths probably proceeds much more slowly than is commonly supposed. Though the existence of some internal source of heat can no longer be denied, doubts may be reasonably entertained respecting its distance from the surface and its intensity.

Whatever difference of opinion may exist as to the condition of the earth's nucleus, it is universally admitted that its surface has long since arrived at a constant temperature, the loss of internal heat by radiation or the cooling of the globe being fully compensated by insolation, or the heat poured on it by the sun. The speed with which a body cools or parts with its heat, depends on the excess of its heat above that of the surrounding medium. As that excess decreases, so does the efflux of heat. If, then, the body receives from an external source heat equal to that efflux, it ceases to cool, its loss by radiation no longer exceeding the heat received. It thenceforward remains at a constant temperature; and such is now the condition of the earth. The various phenomena of climate are therefore at the present day totally independent of internal heat. The cause of all diversities and fluctuations of temperature at the earth's surface must be sought in the circumstances of insolation or influx of solar heat, and in the fickleness of the elements which play the chief part in meteorology, and interfere with the distribution of that heat.

It can hardly be doubted that the stars are suns and shed heat on worlds around them. Many of them are far superior in luminous power, and therefore probably in size also, to our sun. The light of the latter is estimated to be but the 146th part of that of Sirius. Yet, owing to the immense distance of the stars, a trace of their heat can be detected on the earth only by the most delicate instruments. Their number, nevertheless, and their distribution over the heavens, make it likely that they modify in some degree the temperature of space. That temperature was estimated by Fourier, to whom chiefly we owe the theory of heat, to be about −76° Fahr. But it is hard to believe that the temperature of the coldest regions in the midnight sky is not lower than that occasionally experienced in North-eastern Siberia. The experiments of M. Pouillet led him to the conclusion that the temperature of space is about −223° Fahr., a degree nearly attainable by artificial means. Sir J. Herschel arrived by a different process at a very similar result, viz. −234° Fahr. But the heat of the stars, though by us hardly appreciable, may still affect the temperature of the earth through that of space. For low as the latter temperature is, it might, if the stars were extinguished, be lower still, and thus terrestrial radiation or the cooling process of the earth might be rendered more intense.

The sun is the chief source of appreciable heat on the earth. The warmth of the solar rays is as perceptible as their light, and perhaps still more important. It is an interesting question, therefore, whether the sun's heating-power be constant. The spots on the sun which have engaged much attention, appear to be rents in the luminous covering or photosphere. Within these openings may be seen what seem to be piles of clouds around a deep chasm, which terminates in a black line or spot supposed to be the solid body of the sun. The apparent blackness of the spot affords no proof of total darkness, but is rather to be considered as the effect of strong contrast, just as the shadows in a grove at a little distance on a summer's day appear quite black, while within them there is, in reality, broad daylight. The spots rarely appear on the sun's equator, and never near its poles. They break out irregularly in zones a few degrees from the equator, and more frequently on its northern side. They undergo continual change, often enduring nevertheless for several months; and, like hurricanes on the earth, they seem to characterize particular regions.

It was suggested by Sir Wm. Herschel that the appearance of spots on the sun is attended with increase of heat; and proof of this was thought to be found in the low price of wheat whenever the face of the luminary was darkened by spots. But further observation has shown this opinion to be groundless. The total absence or the crowding of spots has no effect on temperature as tested by the productiveness of the year or by ordinary instruments. But Melloni's delicate thermo-electric apparatus proves that the spot is an interruption of the sun's heating surface, and therefore a great increase of spots might be expected to diminish the thermal power of the sun, unless there be at the same time an increased emission of heat from the disturbed surface around them, which is not unlikely.

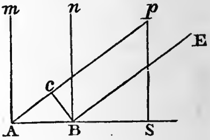
It seems to be established that the solar spots return in force periodically. M. Schwabe, who first made this remark, assumed their period to be 10 years ; while M. Wolf concludes it to be 11·11 years, or to return nine times in a century. Some believe the period of the solar spots to be connected as an effect with the orbital period of the planet Jupiter. Others, on better grounds, connect it as a cause with that of magnetic disturbance.

Apart from the occasional spots, it has been suspected that one side of the sun is hotter than the other ; and as the sun rotates on its axis in little more than 25 days, the regular fluctuations of solar heat from this cause, if there be any, must have the same period. According to M. Buys-Ballot, the thermal difference between the unequal solar hemispheres is 1°·25 Fahr. But it is obvious that the existence of a periodical variation of solar heat to this small amount, and observed only in latitudes where irregular changes of temperature are frequent and considerable, cannot be satisfactorily established without a long course of careful observation.

The amount of insolation or solar heat received on the earth varies in subjection to the following conditions:—1st, the angle of incidence of the solar rays ; 2nd, the length of the day, or duration of continuous sunlight ; 3rd, the heat-absorbing capability of the surface exposed to the sun's rays. The greatest heat of the sun is that which attends the vertical incidence of its rays. The ray that falls perpendicularly on the ground occupies the least surface, and is therefore the most concentrated. It also takes the shortest course, and is therefore least weakened by the interposed atmosphere.

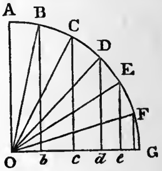
If a sunbeam, *m* A B *n* (fig. 50), falls vertically on A B it has the full width of that space; but if it falls obliquely, as *p* A B *q*, it is reduced to the width *c* B, and on the space A B is more diffused than the vertical beam. It is thus diminished by diffusion in the ratio of A B to *c* B.

Fig. 50.



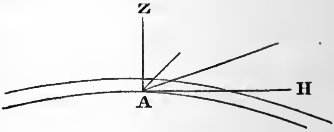
When the quadrant of a circle O A G (fig. 51) is divided into equal arcs, A B, B C, C D, &c., the dividing lines O B, O C, O D, &c. will be all equal, being radii of the circle; but not so the lines B *b*, C *c*, D *d*, &c. drawn from the divided arcs to O G. These are the sines of the angles which they respectively subtend, and decrease with them. Now in fig. 50 *p* A B is the angle of incidence, and *p* S is its sine; and as *p* A is to *p* S, so is A B to *c* B; the loss of heat, therefore, due to oblique incidence varies as the sine of the angle of incidence.

Fig. 51.



It is not by diffusion alone that oblique incidence diminishes the heat of the solar ray. A portion of the ray, increasing with that obliquity, is thrown off by reflection from the atmosphere and is totally lost. Besides, all the heat received by us from the sun must traverse the atmosphere, which absorbs some of it, and the more of it the longer is the track. But the more oblique the incidence, the longer must be that track. On the assumption that the height of the atmosphere is about the hundredth part of the earth's radius, the annexed figure (52) will fairly represent the relative lengths of those tracks. From this it is evident that the vertical ray Z A from the zenith has the shortest course through the atmosphere; while, also falling on it perpendicularly, it loses little by reflection. The ray from the horizon, on the other hand, H A, has much the longest course; and the intermediate rays all cross the atmosphere by longer paths the more acute is their angle of

Fig. 52.

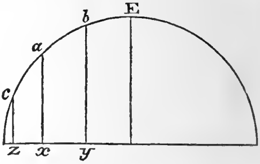


inclination. But the length alone of these lines does not fully account for the abatement of heat which takes place along them. The more the solar ray is inclined to the horizon, the greater is the proportion of it which passes through the lower and vapour-laden stratum of the atmosphere, where heat is absorbed with most avidity. Hence it is that the setting sun in the horizon, when no trace can be seen of cloud or vapour, may be looked at with impunity by the unprotected eye. The diminution of heat due to this cause also is in a ratio not less than that of radius to the sine of the obliquity. Consequently the reduction of heat due to oblique incidence and atmospheric interference taken together must proceed nearly in the duplicate ratio of the sine of the angle of inclination. According to M. Pouillet, the proportion of heat intercepted by the atmosphere is in Paris never less than two fifths, or 40 per cent. By Mr. Forbes, it was estimated to be, on the Alps, 46 per cent.

Now the sun at any given time can be vertical to only one circle of latitude at or between the tropics; on all the rest its rays must fall more or less obliquely, and therefore with heating-power more or less diminished. In general terms the sun's meridian altitude or the angle of incidence is equal to the sum or difference of the latitude of the place and the sun's declination, according as the sun and the place in question are on the same or on opposite sides of the equator; but when the sun is at the equator, that angle is everywhere equal to the complement of the latitude, the sun's zenith-distance being then equal to the latitude of the place. If, then, the sun be supposed to be at its mean place (that is to say, at the equator), the greatest heat received at any point along the meridian will be as the sun's meridian altitude, which varies as the cosine of latitude, or the radius of the parallel of latitude. Lines, therefore, as $c\,z$, $a\,x$, $b\,y$ (fig. 53) drawn from any points (c, a, and b) on the earth's surface perpendicular to its axis, will represent the proportions of heat receivable at those points from the sun at the equator (E).

These proportions will of course change as the sun moves in declination. But the effect will be the same whether the change of zenith-distance arise from the motion of the luminary or of the point in question. If, then, we suppose the point a, fig. 53, to

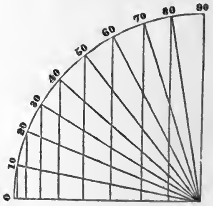
Fig. 53.



move a distance equal to the inclination of the ecliptic (23° 27′) in both directions, or to *b* and *c*, towards and from the equator, then the lines *b y* and *c z* drawn perpendicular to the earth's axis, will represent the amounts of solar heat received by *a* at the summer and winter solstices respectively. But it is evident that *b y* and *c z* must be together always less than twice *a x*; whence it follows that the equinoctial heat for the whole year would exceed the heat of the two solstitial half-years, and that the sun would give more heat to the earth between the polar circles, if it stood still at the equator and had no motion in declination. In consequence of the curved surface of the globe, any point between the equator and polar circle loses more heat by the sun's retreat in winter to the opposite hemisphere than is gained by its approach in summer. Instead of pouring heat constantly on one hemisphere between the poles, the sun, owing to the obliquity of its path, wanders over a hemisphere and a quarter, so as to shed heat annually on 23° 27′ beyond either pole, the heat thus gained by the polar regions being, of course, lost elsewhere. This loss varies as the obliquity of the ecliptic; and consequently, if it be true, as some believe, that a slight improvement of climate has been experienced in Southern Europe within historical time, a natural explanation of that change may be found in the reduced obliquity of the ecliptic. The effect of oblique incidence on light and heat is shown in the following Table:—

Sun's altitude.	Atmosphere traversed.	Light transmitted.	Heat received.
90°	1000	·750	·750
80	1015	·747	·735
70	1064	·736	·691
60	1154	·718	·609
50	1305	·687	·526
40	1554	·640	·411
30	1995	·563	·282
20	2905	·434	·148
15	3841	·331	·086
10	5610	·199	·035
5	10450	·050	·004
0	37850	·002	

Fig. 54.



One half of the globe is always illumined by the sun, and with the light receives heat also. Indeed, owing to the superior magnitude of the sun and the deviation of its beams caused by atmospheric refraction, the illuminated portion of the globe exceeds a half, embracing a zone of about 40 miles in mean breadth beyond the hemisphere. This illumination goes round the earth in twenty-four hours solar time, and is distributed equally in respect of total duration, though not in a uniform manner, over the whole globe. At the equinoxes, when the sun is in the equator, the circle that divides light from darkness passes through the poles, cutting equally and at right angles all the parallels of latitude. Day and night are then everywhere equal. But as soon as the luminary quits its central position, the same circle becomes oblique to the parallels and divides them unequally. Then, in the hemisphere in which the sun advances, the illumined portions of the parallels exceed the dark portions, or the day is longer than the night; the inequality increasing towards the pole, and also as the sun's declination increases. In the other hemisphere the case will be reversed, darkness there gaining the ascendancy in like manner and degree.

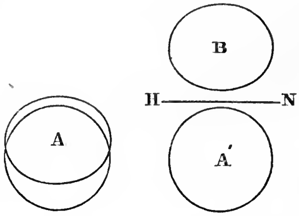
When the sun has reached the solstice or *halt* at the tropic or *turning* line, distant 23° 27′ from the equator, it has by this advance reduced by double that amount, or by 46° 54′ (reckoning from the opposite solstice), the oblique incidence of the solar rays on the zone between the tropic and the pole, in the hemisphere favoured by its presence. This greater addition to the direct power of insolation, together with its prolonged continuance by the increased length of the day, is manifested in the warmth of summer. At the equinoctial line the sun is never more than 23° 27′ distant from the zenith (the slow change in the obliquity of the ecliptic being disregarded); and the length of the equatorial day varies but little. Here, therefore, there is no distinction of seasons—though, as there is no twilight and the wind generally changes at sunset, the difference between night and day is strongly marked. At the tropic, when the sun is in the zenith, the heat is greater than at the equator under like circumstances, because there is not at the former region so dense a canopy of clouds or so humid and heat-absorbing an atmosphere as characterize the latter, and also because the sun about the solstice moves slowly in declination and seems to linger near the zenith. But this great accession of heat is more than counterbalanced when six months later the sun has reached the other tropic 46° 54′ distant. The consequence of this change is that the mean annual heat of the tropic is less than that of the equator, although the temperature of the latter line is evidently reduced by peculiar circumstances much below that otherwise due to its central position. Yet at the tropic the length of the day varies but little, and the seasons, not fully contrasted below the 30th parallel of latitude, are distinguished only as the *wet* and the *dry*, not as summer and winter.

The increase of temperature in high latitudes brought about by the more direct incidence of the sun's rays, is limited by the confinement of the luminary between the tropics. The change in the angle of incidence can never exceed the breadth of the tropical zone or 46° 54′. But the inequality of day and night, or of sunlight and the privation of it, passes through every possible gradation, increasing from the equator towards the pole. While one pole is fully illumined, the other is left in darkness, each having continued sunlight for six months and continued darkness, or rather twilight, for an equal period. At the polar circle (lat. 66° 33′) the wintry days grow shorter and darker till at the winter solstice (the 21st December for the Northern hemisphere) the sun appears on the horizon only for two or three minutes. Thenceforward it gradually ascends higher; and when in three months or at the vernal equinox it arrives at the equator, it has attained at the polar circle the altitude of 23° 27′, and remains twelve hours above the horizon. And now comes the polar summer. The day rapidly lengthens till on the 21st June (the summer solstice) it attains the length of 24 hours, the sun rising at noon to the altitude of 46° 54′, and at midnight just touching the horizon.

At the pole itself the sun is seen for the first time in the year at the vernal equinox, or in March (in the northern hemisphere); and once above the horizon, it continues there, moving round the heavens in a gradually ascending spiral path till it attains in three months the altitude of 23° 27′. It then begins to descend the same spiral path and terminates the long polar daylight of six months by setting at the autumnal equinox. While thus setting for the northern pole it rises for the southern.

The length of the day is usually reckoned from the instant when the middle point of the sun rises above the horizon to the instant when the same point sets. But the mean breadth of the sun's disk is 32 minutes. Consequently half of the sun (16′) is above the horizon before the commencement of the astronomical day, which is followed as well as preceded by sunlight. Refraction also raises an object on the horizon about 36 minutes. Hence the motion of a heavenly body descending to the horizon is apparently retarded and its figure abridged by the increasing refraction. The whole disk of the sun, A (fig. 55), is seen raised and converted into an ellipse by refraction, when at an altitude of about 20°. B shows it apparently touching the horizon H N, when the orb A′ has really set and is four minutes below that line. Thus sunlight is prolonged while the heavens move through 52 minutes of space. The time required by the sun to ascend or descend an altitude equal to its own semidiameter depends chiefly on the inclination of its path to the horizon. At the equator, where it moves at right angles to the horizon, the addition to the length of the day or to sunlight from the causes just explained is but 3½ minutes. But at the pole, where the sun's path makes an acute angle with the horizon, the same causes add 53 hours to the otherwise long season of uninterrupted sunlight, which there extends to 187 days, 178 remaining to the long and gloomy winter.

Fig. 55.



The apparent path of the sun, in reality traced in the heavens by the earth's revolution on an axis inclined to its orbit, is a continuous spiral line which cannot be correctly represented in any figure, because, the 365 lines of that spiral, back and forward, occupying a space less than the 30,000th part of the sun's distance, no lines could be drawn fine enough to represent it in its true proportions and within reasonable limits. But all thoughts of just proportion and exact delineation being thrown aside, figures may be devised which will give some idea of the varied aspects of the sun's course in different latitudes of the earth.

The position of the globe in respect to the celestial horizon is generally in maps accommodated to the place or country in which the map is made. That place is always at the summit; and upon it therefore depends the inclination of the earth's axis and the equator to the horizon. Thus, London being in lat. 51° 30′ 48″, the north pole is placed at that altitude above the horizon, to which the equator is inclined at the complementary angle of 38° 29′ 12″. But the inclination of the earth's axis of rotation at an angle of 23° 27′ to the plane of the ecliptic or orbit of revolution is an absolute fact, unchangeable in every position of the globe. While the earth rotates in 24 hours, the sun seems to go round the heavens; but the earth at the same time advancing in a path inclined to its equator, the sun's right ascension also is thereby changed, and the luminary appears to move round in a spiral line, ascending in half a year 23° 27′ from the equator, and then descending the same distance below it. The earth's orbit is described in a rectilineal plane (fig. 56), which may be represented by the straight line *a b* inclined to the equator. From the opposite side it appears as *a′ b′*. These lines, drawn as seen from opposite points of view, are in fact the sides of the orbit between the solstices, *a* coinciding with *a′*, *b* with *b′*. They represent respectively the ascending and descending half of the orbit, viewed from the same point in the centre; and making each an angle of 23° 27′ with the equator, they embrace an angle of 46° 54′ and mark the limits of the sun's movement on the meridian. If, then, within these limits we draw spiral lines to represent the sun's diurnal revolutions in the course of a year, and suppose the earth to be at the central point, we shall have a figure capable of illustrating the phenomena of insolation in different regions of the earth.

Fig. 56.

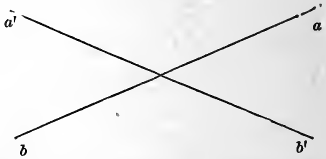


Fig. 57.

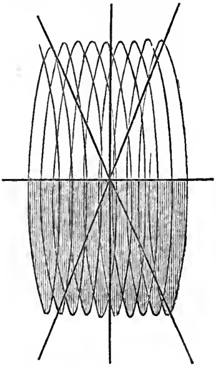


Fig. 57 shows the configuration peculiar to the equator. The heavenly bodies all rise vertically; and while the sun is at the zenith, all perform half of their courses in daylight. Night and day are then perfectly equal. The sun goes in three months to the solstice A, goes back again to the zenith, passes on to the solstice B, and completes the year by returning to the zenith, from which it is never distant more than 23° 27′. At the tropic (fig. 58) the sun is at the zenith but once in the year at one solstice, and at the other 46° 54′ distant from it. In lat. 51° 30′ (fig. 59) the sun when highest is still 28° 3′ from the zenith, and in midwinter is 74° 57′ from it, rising little more than 16° above the horizon. The length of the night varies from 8 to 16 hours. The polar circle (fig. 60) has, on one day of the year, sunlight for only two minutes, and six months afterwards a day of 24 hours. The sun at the pole (fig. 61) rises but once and sets but once in the year. When risen it goes round the heavens nearly parallel to the horizon, and never attains an

Fig. 58.

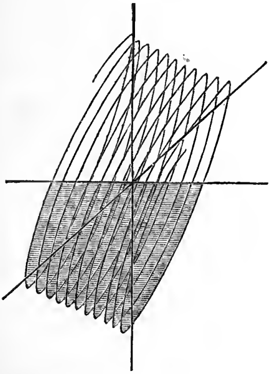
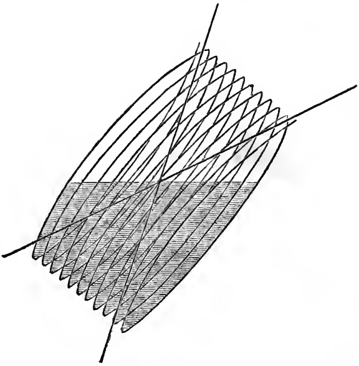


Fig. 59.



altitude exceeding 23° 27′. So near the horizon it is dimmed by perpetual fogs. The setting of the sun at the end of September is succeeded by a very long twilight.

Fig. 60.

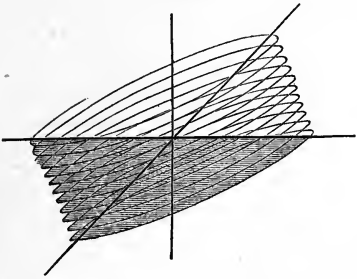
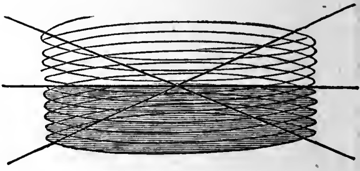


Fig. 61.



Earthy minerals being in general bad conductors of heat, the solar heat that falls on the ground penetrates but a little way below the surface. Its rate of progress in the first instance is said to be an inch in about 32 minutes ; but it rapidly abates, so that at Brussels the heat of summer takes six months to descend to a depth of 24 feet. At that depth the highest temperature of the ground occurs on the 12th December, the lowest on the 18th of June. Hence it is that the water of springs is so often found to be warm in winter and cold in summer. It is collected at a depth which the temperature of the surface does not reach in less than six months. The annual changes of surface-temperature probably do not penetrate the ground in middle latitudes to a depth exceeding 80 feet. But the depth to which the solar rays may affect the ground depends much on the nature of the soil. Heat is propagated more rapidly in compact sandstone than in loose sand, and in the latter than in trap-rock. It makes its way more easily by the lines of stratification ; and consequently horizontally stratified rocks are comparatively impervious to solar heat. It must be remembered also that the internal temperature of the ground at any place is liable to be affected by water passing through it. Water from above will generally depress the temperature, from below will raise it. The daily variations of temperature rarely penetrate the ground in Europe beyond a depth of 3 feet.

About the equator the diurnal variation of temperature, inconsiderable in the air, is quite imperceptible in the ground. This constancy is due to the comparative invariability of the sun's heating-power in the torrid zone. Where the sun is in or near the zenith, the penetrating power of its rays must be greatest; and therefore the temperature of the ground must depend more entirely on the sun between the tropics than elsewhere. This remark will serve to explain M. Boussingault's observation, that in Equatorial America the temperature of the ground does not seem to increase downwards but rather to decrease. Now the fact is that in Europe, outside of the polar circle, the temperature of the ground does not in summer increase downwards from the surface, but decreases down to the line of constant temperature, the limit of external influence, and thence increases. In the torrid zone, as elsewhere, the heat of the ground, so far as it is derived from the sun, must decrease downwards. But that decrease must come to an end at a depth perhaps of 120 or 150 feet; and thence temperature increases towards the centre.

The consequences of the oblique incidence of the solar rays did not escape the observation of the ancients. Claudius Ptolemy divided the earth into climates (*κλίματα*, or inclinations)—that is, into zones differing to a certain amount in the length of the longest day. His first climate extended from the equinoctial line to lat. 4° 15′; his second, differing from the preceding by a quarter of an hour, extended to lat. 8° 25′. But as he proceeded towards the pole he was obliged to allow his zones wider limits of time. His calculations were all inaccurate; and his climates have manifestly little connexion with climates in the modern sense of the word; for we now mean by climate not a certain inclination or obliquity of sunlight, resulting from latitude and the sun's declination, but a natural character, of which that inclination is always an important but often not the most influential element. The division of the earth into hourly zones, their halves or quarters, having no practical value soon fell into disuse and does not deserve revival. The length of the longest day in different latitudes, with its rapid increase towards the pole, is shown in the following Table.

Lat.	Longest day.		Lat.	Longest day.	
°	h	m	°	h	m
0	12	0	40	14	51
5	12	17	45	15	26
10	12	35	50	16	9
15	12	53	55	17	7
20	13	13	60	18	30
25	13	34	65	21	9
30	13	56	66 33′	24	0
35	14	22			

Beyond the polar circle (66° 33′) the sun's stay above the horizon is measured not by hours but by days. Thus the luminary does not set in

		Northern Hemisphere.	Southern Hemisphere.
lat. 70°	during	65 days.	60 days.
75	„	103 „	97 „
80	„	134 „	127 „
85	„	161 „	153 „
90	„	186 „	179 „

The summer of the northern hemisphere is about 8 days longer than that of the southern, because during the former the earth, being in aphelion or the part of its orbit furthest from the sun, moves with abated velocity. The passage through the perihelion (the nearest part of the orbit), in the summer of the southern hemisphere, is performed more rapidly.

As to the actual heating-power of the sun, it is not easy to find a convenient mode of measuring and expressing it. M. Pouillet concluded it to be 1° ·7633 Cent. in one minute on a square centimetre, or about 20° Fahr. on the square inch. Sir J. Herschel ascertained, by careful experiments made at the Cape of Good Hope, that the vertical rays of the sun under a clear sky can melt 0·00754 inch of ice in a minute; and combining this result with that obtained by M. Pouillet in a like experiment, he adopts the mean of both observations, or 0·007285 inch of ice per minute, as the measure of the melting power of the vertical sun. Now it is worthy of remark that the results obtained by these two experimenters agree in reality still more than in appearance.

M. Pouillet, observing in Paris from May to September, found the figures 0·00703; Sir J. Herschel, in the southern hemisphere about the 1st January (when the sun is in perigee) found 0·00754. But the sun in perigee being at its least distance from the earth, the summer heat of the southern hemisphere exceeds at any moment that of the northern in the ratio of 16 to 15. If the figures 0·00754 therefore be reduced by a sixteenth they will become 0·00707, or nearly the same as those found by M. Pouillet. Hence the assumed measure 0·007285 may be accepted as the true mean for the whole earth. At such a rate an inch of ice would be melted in 2 hours 17 minutes, a foot in 27 hours 24 minutes of sunshine, and 157 feet in a year. This refers to solar rays vertically incident and otherwise undiminished. M. Pouillet, again, arrived at the conclusion that the solar heat annually poured on the earth would suffice to melt 101 feet of ice uniformly spread over its whole surface. From these data it may be concluded that since 142 degrees Fahr. of heat are required to melt ice, the perpendicular rays of the sun falling on a square inch of ice, can communicate to it something more than one degree of heat in a minute.

CHAPTER VII.

Terrestrial Radiation—depends on the Character of the radiating Surface—varies with Season and state of the Sky—proved by Experiment—lowers Temperature—Dew and Hoarfrost.—Radiation varies as Insolation.—Making of Ice, in India and China.—Attempts to measure Radiation—its Effects on the Earth—and on the Moon.

As heat finds its equilibrium on the earth by radiation from the warmer to the cooler bodies, so also it continually flows and reflows between the earth and the heavens. As day and night alternate, so also do heat and cold. Lengthening nights bring on the cold of winter; long days the season of light and warmth. The changing altitude of the sun on the meridian gives rise to the diurnal changes of temperature; the varying length of the day accounts for the annual vicissitudes of season. At dawn begins the influx of heat, which increases till the sun at noon attains its greatest altitude. The heating power of the luminary having then reached its maximum, begins to decline; yet the ground, which is the immediate source of heat to the air, having become heated, the temperature exceeds for some time the loss incurred by radiation, so that heat continues to accumulate until radiation overtakes the now relenting march of sunshine. This, in middle latitudes and at the level of the sea, generally takes place a little after 2 o'clock. At that moment occurs the daily maximum of heat. Radiation of heat to the sky then begins to predominate as temperature declines, and under favourable atmospheric conditions goes on without check till sunrise, just preceding which occurs the greatest cold or daily minimum of heat.

Radiation being from its nature active in proportion to the heat that feeds it, follows temperature at some distance in the early part of the day; but increasing with the influx of heat, gains the upper hand soon after the latter has begun to decline. The daily maximum of heat therefore follows noon at a short distance. But at night radiation has no antagonist, and its effects go on accumulating till sunrise, however long that may be deferred. Radiation may be in action during the whole 24 hours; whereas sunshine goes through all its phases of increase and wane, in general in half that time, and then disappears. Something like this inequality in the daily conflict between insolation and radiation may be found also in the conditions of their annual struggle. The sun being confined to a certain zone of the heavens, the effect of its rays on the greater portion of the globe must be always diminished by oblique incidence. But radiation on the other hand is subject to no such reduction, being everywhere directed to the visible heavens, though with most intensity to the zenith. Yet the solar warmth is never wholly lost, nor does the earth sink to the temperature of remote space. For the sun always shines on one half of the earth's atmosphere, and as that atmosphere incessantly circulates, it serves for all parts of the globe as a communication with the source of heat.

It has been already stated that free radiation of bodies depends much on the character of their surface, and that the characters most favourable to radiation, viz. roughness, fibrous texture, &c., are really those which imply an amplification of surface. Radiation from the earth therefore varies not only with the mineral constitution, but also with the configuration of the ground. That which is perfectly flat, bare and smooth radiates least. Uneven ground presents more surface on an equal area, and vegetation always seeking by its development to hold intercourse with the atmosphere, greatly facilitates the process of radiation.

The radiation of heat from the ground attains its maximum at the end of a long night, under an ample extent of perfectly clear sky. It is less therefore in a close valley or among trees than on an open plain. If a thermometer be laid in cotton wool on long grass, exposed to a cloudless nocturnal sky, and its indications be compared with those of a thermometer suspended at some distance above the ground, it will be seen that the air is coolest next the ground, that the temperature increases rapidly from the ground to the height of 4 or 5 feet, and thence more and more slowly up to 12 or 15 feet. Care must be taken to screen the thermometer from the sky; otherwise the glass, being a free radiator, will show a temperature below that of the surrounding air. The greatest difference between the thermometer on the ground and that in the air, recorded in the careful experiments of Mr. Glaisher, is 28°·5; but under a clear sky in our latitudes a difference of 20° occurs frequently. In low latitudes with dry climate the effects of nocturnal radiation are still greater, effecting in some cases a refrigeration of at least 80° Fahr. Haze or clouds diminish radiation, which ceases altogether when the sky is completely covered. If a delicate thermometer placed with its bulb in the focus of a concave, well-polished silver mirror, be presented to the blue sky, while screened from all other objects, it will fall several degrees below the temperature of the air, but will rise the moment the axis of the mirror is turned to a cloud, and in proportion as the cloud is near. Any terrestrial object entering its field of view (even, as Sir J. Herschel relates, the summit of a snow-clad mountain will) raise its temperature.

It has been hastily concluded from the observations of Mr. Daniell that radiation varies with the altitude of the sun; for in England it is highest in June, though the temperature is greater in the three following months, and lowest in January. But it must be remembered that the summer rains fall heavily in July, and the greater radiation in June is probably not attributable to the sun's altitude, but rather to the favourable union of temperature, dry atmosphere, and clear sky. Radiation of the surface increases in intensity with elevation above the level of the sea, or as the atmospheric interference decreases. Towards the equator it generally decreases, owing doubtless to the abundant vapour of a warm atmosphere. The cooling-power of radiation depends entirely on the clearness of the nocturnal sky, perfectly free from cloud or vapour. Hence the intense cold felt in dry countries. Radiation, like light, is most intense when acting from the zenith, in which direction there is least atmosphere interposed. Plants protected overhead will never suffer by the cold that may come from a low altitude. The cold of radiation penetrates but a little way into the ground; at 8 inches below the surface the nocturnal temperature of the ground may often be found doubled.

The results of Mr. Daniell's observations to determine the nocturnal radiation in London, continued for three years, are shown in the following Table :—

	Mean temperature of air.	Mean cooling of the ground by radiation.	Absolute maximum of cooling.
	° Fahr.	°	°
January	32·6	3·5	10
February.........	33·7	4·7	10
March	37·7	5·5	10
April	42·2	6·2	14
May...............	45·1	4·2	13
June	48·1	5·2	17
July..............	52·2	3·6	13
August	52·9	5·2	12
September	50·1	5·4	13
October	42·1	4·8	11
November	38·3	3·6	10
December	35·4	3·5	11

From this it appears that in nine months of the year, omitting incidental and irregular extremes, the ground at London may sink at night to the freezing-point, and in the other three months (July, August, and September) it may fall to within five degrees of that point. In tropical climates radiation at great elevations is extremely active. General Sir Edward Sabine found that in Jamaica, near the sea-shore, radiation never lowered the thermometer more than 11½ degrees, but at the height of 4000 feet, 18 degrees. In South America also, according to M. Boussingault, radiation at moderate heights never depresses the thermometer more than 10 or 11 degrees, but at great elevations it makes the snow at the surface sink 25 degrees below the temperature of the surrounding air. The effect of radiation on snow was carefully observed on the "Grand Plateau" of Mont Blanc by Messrs. Bavais and Martin; and they found that while the temperature of the air was from 24°·8 to 21°·2, Fahr., the surface of the snow usually fell at least 23° lower, and varied from 0°·6 to 4° Fahr. It was remarked by Capt. Scoresby that in the polar regions the sea never freezes under a clouded sky, when the thermometer is above 29°; but under a clear sky ice is formed when the temperature of the air is at 32°. In this latter case the surface of the sea is doubtless cooled down by radiation to a temperature much below that of the air.

To make experiments on radiation successful, care should be taken to lay the thermometer on a substance possessing great radiating and little conducting power. The relative fitness in this respect of the following substances has been determined by Mr. Glaisher and estimated in numbers, that of long grass being taken for the standard:—

Raw white cotton-wool	1222	Snow	657
Flax	1186	Sheet iron	642
Raw silk	1107	Paper	614
Long Grass	1000	Slate	573
Lampblack powder	961	Garden-mould	472
Flannel	871	River-sand	454
Glass	864	Stone	390
Sheet copper	839	Brick	372
Charcoal powder	776	Gravel	288

From this Table it appears that under all varieties of conditions cotton-wool is found to be the best radiator. It is remarkable that Mr. Glaisher assigns a higher radiating power to snow than to sand, whereas in all Patrick Wilson's experiments sand was invariably colder than snow. Is this to be ascribed to the difference between dry and wet sand? or may we not rather assume that the radiating power of snow depends on its condition, being greater in fresh snow, retaining its crystalline structure, than in that which is compressed?

Plants of every kind are highly favourable to radiation, because the functions of vegetable life demand ample surface, and plants unfold their leaves only to spread surface to light or to be in contact with the air. Humboldt remarked that in the plains of Venezuela and on the banks of the Orinoco, the air was cooler among the leaves of plants. But little notice has been taken of the influence probably exercised by great forests in bringing about vicissitudes of temperature in warm climates. The coolness of a wood is perhaps attributable, not so much to the exclusion of the solar beams as to the descent of cold air from the summit-level of the trees, where the radiation must be intense.

The effects of radiation in lowering temperature on the ground were investigated in the last century by Le Roy of Montpellier (1751), by Pictet and Prevost of Geneva, and by Professor Patrick Wilson of Glasgow. By their researches all the phenomena were brought to light, but not in all cases perfectly explained. When Dr. Wells therefore, in 1812, published the collective results of these inquiries in a popular volume (on Dew), he obtained at once the fame of a great discoverer. At that time it was generally believed that the cold of night or of early morning is caused by the deposition of dew; whereas in reality dew is the effect, and not the cause, of cold: it is the humidity wrung from the air by the cold produced at the surface of the ground by radiation. The quantity of vapour floating at any time in the atmosphere depends on the temperature of the latter. A certain quantity is sustainable at a certain temperature; and the air with this supply of humidity is said to be saturated. But if it be cooled down below the point of saturation or dew-point, the excess of vapour in it must be condensed and fall in the liquid state as dew. If the temperature of the radiating surface is below the freezing-point, the dew being congealed, becomes hoarfrost. Hence it is that heavy dews and hoarfrosts occur only under clear and unclouded skies, and that the full moon (which tends to produce, and very often shines in, an unclouded sky) is vulgarly suspected of exercising a blighting influence. Dew, then, is the vapour diffused through the air in contact with or near the ground, and forced from it by the cold of the latter. Hoarfrost is a like deposit congealed. At an early hour on May mornings proofs of the nocturnal frost may often be seen in minute spicula or needles of ice collected about the points of thorns, because sharp points, having much surface in proportion to mass, are peculiarly fitted for radiation—and chiefly on the gooseberry-bush, perhaps because its thorns are near the ground. Hoar frost is never seen on smooth and rounded surfaces, such as that of the ash tree, but only on points and sharp edges.

From what precedes it will be evident that under a clear nocturnal sky the warmth of the ground only increases the energy of the radiating process and the consequent refrigeration. Hence the extreme morning cold so often unexpectedly experienced by travellers in hot and dry countries. In many cases the illness ascribed to malaria is in truth only a severe cold caused by the sudden and excessive fall of temperature at sunset, and rendered fatal by injudicious treatment. Ice is occasionally found on the Nile near Syene, at the southern limit of Egypt; and it is well known to the inhabitants that this phenomenon follows a low Nile or unusually dry year, the increased refrigeration at night being due to the total absence of haze or atmospheric vapour. We are told that the water-skins of caravans in the Sahara, or burning deserts of Africa, have often during the day a temperature exceeding 100° F. and yet are frozen before morning; and M. Rohlfs, the celebrated African traveller, states that at Morzuk in Fezzan (lat. 25° 50′ N.), where the heat in the shade during the day is often 130° F., the thermometer in December ordinarily falls, just before daybreak, to 25° F., or 7 degrees below the freezing-point.

In the plains of India and China the people have known for ages how to take advantage of radiation to make ice on a great scale. Ice an inch and a half thick is thus made at Benares. But it is made also much nearer to the sea-shore and under a more humid atmosphere. A recent account of the production of artificial ice at Hooghly near Calcutta furnishes the following particulars. In level fields fully exposed to the sky are marked out quadrangular beds, 120 feet long and 20 wide, extending from west to east. These are excavated to a depth of two feet, and when perfectly dry are filled with sheaves of rice-straw, over which again is spread a quantity of loose straw. Thus is formed a nonconducting bed of a good radiating substance. Towards evening are arranged in rows on this bed shallow dishes of unglazed clay, about 9 inches in diameter, and so porous that they become moist throughout as soon as water is poured into them, and begin to evaporate. The quantity of water in each dish varies from two to eight ounces according to the state of the sky; the average is perhaps under four ounces. When the dry land-wind from N.N.W. blows gently and steadily, the water is sometimes all frozen ; but this rarely happens. As soon as congelation is observed taking place in any dish, small films of ice from it are dropped into the other dishes, which hastens the process. One bed contains about 4600 dishes and nearly 240 gallons of water, producing on a favourable night 10 cwt. of ice or about half the weight of the water, much of which is lost by evaporation. So powerful is radiation on clear nights in tropical climates that the thermometer at Hooghly has been seen to fall 13°·5 in 4 minutes at sunset. At the ice-pits the temperature on the straw is 27° F., while three feet higher it is 48°.

The radiation of heat from the earth to the heavens is obviously a particular case of the general equalization of temperature that takes place among all bodies, and proves that the earth's temperature exceeds that of surrounding space. But of that space and its temperature we have no clear idea. According to M. Pouillet the mean temperature of our atmosphere is, in its upper regions much below, in its lower regions much above, that of general space. But what is the temperature of general space? It was supposed by Fourier to be −76°, or little colder than the winter in Yakutsk or Melville Island. Poisson, again, concluded that the temperature of Paris, if the sun were extinguished, would be not lower than 8°·6 Fahr., or only 23°·4 below the freezing-point. He ascribed much importance to star-heat, and even thought that the higher temperature of the Northern hemisphere might be accounted for by the greater density of the stars in the northern heavens. But subsequently M. Pouillet found from repeated observations with the actinometer that the temperature of celestial space lies between −283° and −174° Fahr. (175° and 114° Cent.), and he finally adopted for its expression the mean −223°·6 F. (−142° C.). Sir J. Herschel, again, taking the mean between his own and M. Pouillet's observations, fixed it at −234° F. These determinations must be regarded only as rude approximations where accuracy is unattainable. The temperature of space can never be found apart from that of the atmosphere, which is extremely variable. M. Pouillet, assuming that the temperature of general space is much above the absolute zero, concluded that it must be derived from the stars, and he even went so far as to assert that the heat of the stars is five sixths of that of the sun. He seems to have miscalculated through forgetting that a high temperature can be brought about only by a rise in the scale, and not by a multiplication of low temperatures. If the heat communicated by each star be 32°, then the heat of 10,000 stars will be no greater than that of so many icebergs.

The rate at which the earth cools in the presence of an unclouded sky being once experimentally determined, we are enabled to calculate the length of time which has elapsed since it began to cool down from a higher temperature. The knowledge already acquired of the power of radiation, together with the experiments made by Bischof on the rate of cooling of a globe of basalt two feet in diameter, warrant the conclusion that since the time when the temperate zone of the earth, which now has a mean temperature of 50°, had the temperature of the equator, or 81°·5, there must have elapsed 1,298,000 years at least, besides the many ages during which the earth has since remained at a constant temperature. Fossil forms of vegetation characteristic of equatorial heat are found even far within the polar circle. They are memorials of plants which cannot have flourished where their remains are now found within less than a million and a half years or 15,000 centuries. Yet they belong to a recent period of geological time. Imperfect as our retrospect into the past must necessarily be, we are yet enabled by considering the cooling of the earth, to catch a glimpse of its past history, and view it with certainty, though from an imperfectly measurable distance.

The moon stands in some respects in strong contrast with the earth; for it has no ocean, no atmosphere, no vapour nor clouds, and therefore is ever exposed to unmitigated solar heat, or to incessant and active radiation. It has been calculated that the side of the moon facing the earth has, a few days after full moon, a maximum temperature of 750° F. (400° C.), and again, soon after new moon, sinks to −187° F. (−122° C.). The heat of the moon sensibly affects the earth's atmosphere, though it does not reach the ground; and since therefore it has only the effect of dissipating the vapour that would screen the earth, it may, by intensifying nocturnal radiation, occasion a loss of heat.

The earth thus suspended between the cold of space and the heat of the sun, has a temperature depending on the combination of these influences, and, as the one or the other of them predominates, varies from place to place. Some points near the pole experience annually the low temperature of −70°. Others near the equator occasionally experience a summer heat of 130°. But on the earth collectively heat prevails. The zone that embraces 30 degrees on each side of the equator, forms half of the globe ; and of this half all, save very high mountains, enjoys a decidedly warm climate. The land in this broad zone is clothed in luxuriant vegetation by the abundant heat, light, and moisture ; while the excess of warm oceanic vapours is wafted to less-favoured climes.

CHAPTER VIII.

The Atmosphere—its Composition—Constancy—Incidental Gases.—Carbonic Acid Gas—Vapour—Law of Mariotte.—Atmospheric Pressure.—The Barometer—Weight of the Atmosphere—its Height—affected by Temperature—and by the Earth's Rotation—Periodical Fluctuations.—Table of Atmospheric Pressures.

THE atmosphere (a name derived from ἀτμὸς, breath or vapour, and σφαῖρα, a sphere), or ocean of air enveloping the earth, is a mixture of two gases, namely nitrogen and oxygen, in the proportion of 79·19 volumes of the former to 20·81 of the latter, or in weight—

Nitrogen......... 77   Oxygen 23

Pure atmospheric air being taken as the standard in measuring the density of gases, its specific gravity is 1; that is to say, it is the unit employed in ascertaining the specific gravities or comparative weights of other gases. Nitrogen, though it enters into the composition of all organized bodies, is distinguished by its want of affinity or disposition to combine, and is the most abundant of all gases in an independent and uncombined state. It is the element which chemists can most confidently pronounce to be original and not a product. Oxygen, on the other hand, is the most active chemical principle in nature, perpetually circulating and entering into combination, being consumed by respiration or by combustion, and more slowly absorbed in the decomposition of bodies and the oxidation of metals. In an atmosphere of pure oxygen gas, vital action would go on so fast as to terminate in an instant, destroyed by its excessive energy. The pure gas, instead of feeding and prolonging the existence of flame, would explode at its contact, so that flame and atmosphere would be extinguished together. But intimately mixed with a gas of neutral or negative character, and which preponderates in the ratio of nearly 4 to 1, the oxygen has its vivacity moderated. Its particles, separated and caged like the flame in the safetylamp, go forth to action in single file, and not in phalanx; and thus the power which, left to itself, would be expended at once, is rendered stedfast and continuous. Nitrogen, called also azote, in thus diluting the oxygen of the atmosphere, serves a most important purpose, and at the same time contributes to the material of all organized bodies, though chemists are still unable to trace its course or detect its mode of combination. They assume, however, that plants have the power of abstracting nitrogen directly from the atmosphere, restoring by their decomposition what has thus been taken. The circulation of oxygen and the repair of its consumption are chiefly effected by vegetation, the green leaves of plants having the power, with the aid of light, of decomposing the carbonic acid conveyed in water to the roots, of separating its elements, and of giving off the oxygen gas thus liberated, while they retain the carbon.

These two gases, being not chemically combined but merely mixed together in the atmosphere, are free to enter into combination with other bodies, and since oxygen is largely consumed by all that breathes, lives or burns, it is natural to suppose that the quantity of it in the atmosphere is liable to local fluctuation. Yet, owing to the great extent of the atmosphere and the rapid diffusion of gases, this fluctuation lies within such narrow limits as to escape ordinary observation. Air taken from the open atmosphere on land or at sea, on desert plains, mountain-tops, or populous cities, collected in deep mines or brought down by aëronauts from above the clouds, is found to be everywhere appreciably the same. The expert chemist alone can detect some slight changes in its composition. Water absorbs atmospheric air with a preference for its oxygen; and consequently the air disengaged from the sea or from rain contains 32 instead of 23 parts in a hundred of the latter gas. When the ocean is compelled by increased temperature to give up some of its imprisoned air, which is estimated to amount to about a 300th part of the atmosphere, it restores the full proportion of the nitrogen absorbed, but only a part of the oxygen. Of the latter it takes from the atmosphere more and gives back less than a fair share; and hence the deficiency of oxygen immediately over the sea sometimes amounts to a fifth per cent.

It is a peculiar characteristic of gases that, though elastic and resistent to solids and fluids, they are mutually penetrable, and when mixed together diffuse themselves through one another with more or less speed according to their density, ultimately comporting themselves each as if the others had no existence. If a light and a heavy gas be thrown together, they do not arrange themselves according to weight as oil on water or water on sulphuric acid; but the light gas goes to the bottom and the heavy gas to the top, in the same proportions as they would separately have exhibited. If two vessels containing different gases be made to communicate by a glass tube, the gases will be found in a short time completely intermixed. But if they differ in density they will differ also in the power of diffusion, the activity of the lighter gas surpassing that of the heavier in the inverse subduplicate ratio of their densities. Thus oxygen being sixteen times as heavy as hydrogen, the latter will diffuse itself with four times the speed of the former; and a piece of fine membrane fixed in the tube connecting them, while it will not hinder the diffusion, will show by the convexity of its surface towards the oxygen, the superior pressure of the current from the opposite side. From this it appears that the union of oxygen in the atmosphere with a somewhat lighter gas is not without a purpose; for, on account of its greater density, it must always follow the nitrogen in diffusion, and can never, therefore, escape from that state of dilution which so much enhances its virtue.

From what precedes it may be concluded that, if we had before us columns of equal height of two gases differing in density, we should find the column of heavier gas more compressed at the base, and decreasing upwards in density more rapidly than the lighter gas, and also that if the two gases were mixed together the distinct internal arrangement of each of them would remain as thus described. Hence it follows that oxygen, being the heavier of the two gases in the atmosphere, must be relatively more dense at the lower level and less dense at great altitudes; and this seems to be countenanced by the observations of M. Boussingault at different elevations, which gave the following results :—

	Height.		Oxygen per cent.
At Bogotá	8694 feet.	....	20·65
Ibaque	4345 ,,	....	20·70
Mariquita ...	1797 ,,	....	20·77

Mixed with atmospheric air in comparative minute quantities are two other gases not less necessary for vegetable life than those already mentioned, though much less voluminous, being required only for the maintenance of solid structure, the particles of which, not being fleeting and in ever rapid circulation, are more easily supplied. These are carbonic acid gas and ammonia or hydrate of nitrogen. All the woody fibre and all the fecula or nutritious substance of plants are furnished to them from these two gases, chiefly by means of the atmosphere. The proportion of carbonic acid gas ordinarily found in the air is about 4 parts in 10,000; but it varies considerably, being less in winter than in summer, and on land less by day than at night. These fluctuations are attributable to the alternating processes of vegetation. At sea, the nocturnal absorption of gases by the water and their subsequent disengagement by the heat of the sun reverses the course of variation, and the carbonic gas is more abundant by day.

That this, the heaviest of all gases, its specific gravity being 1·524, should be found disproportionately abundant at great elevations and even above the limits of vegetation, is a remarkable fact, first observed by De Saussure, and since confirmed by Schlagintweit. The latter found the proportion of carbonic acid on the flanks of Mount Rosa, at a height of 10,418 feet, to vary from 5·9 to 9·5 per 10,000. This hitherto unexplained excess of a heavy gas at great elevations will cease to appear marvellous when it is considered that carbonic acid gas continually deposited from the clouds can accumulate only where there is nothing to consume it, and that it is found in abundance not at great altitudes generally, but only on the flanks or summits of mountains, where it has fallen above the limits of vegetation. It is true that on the highlands of New Granada carbonic acid gas has been found to form 12 parts in 10,000 of the atmosphere, in Esperanza 25, and in Bogotá even 49 parts, or twelve times the ordinary amount. This remarkable excess, however, is probably due to volcanic exhalations, or rather to the burning down of forests, called by the Spaniards "las quemas," practised in those countries in the dry season. Air containing a tenth part of carbonic acid gas destroys life instantaneously; a much less proportion of it suffices to extinguish flame and seriously impede respiration.

Ammonia can be detected in the atmosphere only in combination with carbonic acid gas (that is to say, as a carbonate), or, after thunder-storms, as a nitrate. Wherever atmospheric electricity is much developed and lightning frequent, there the walls and bare ground are sure to be covered with nitre. But in rain, snow, and frost, ammonia appears in comparative abundance, and particularly in fog, to which it often imparts a disagreeable odour. The proportion of it in the atmosphere cannot be estimated at more than a millionth. But little as this may seem, it is found on calculation to be amply sufficient. The atmosphere owes its supply of ammonia to the decomposition of organized bodies, and its carbonic acid gas also to decomposition, respiration, the exhalation of plants, and the subterranean sources, whence the gas reaches the surface either through volcanic fissures or by means of springs. For since water invariably absorbs its own volume of the gas, the latter is taken up in greater quantity the greater compression it has undergone; and consequently the deeper the source whence it issues the more is the water surcharged with gas on reaching the surface.

Besides these two gases there is always mixed with the atmosphere more or less of aqueous vapour, a most important addition, the nature of which shall be fully treated of further on. Here it will be sufficient to remark that the carriage and diffusion of aqueous vapour may be reckoned among the chief functions of the atmosphere; for without it the earth would be an arid waste. The proportion of vapour in the atmosphere at any time varies according to the temperature and other circumstances. With the thermometer at 80° Fahr., and in sunshine, it may amount to a thirtieth part in weight; but its unstable nature is the chief cause of the fickleness so often imputed to the skies.

Boyle was the first to make known the law regulating the elasticity of the air, a law subsequently extended to all gases and now named from Mariotte, who announced it to an attentive public in distinct and adequate terms, viz. that the density is always proportional to the sustained pressure. From this it follows that, the density being inversely as the volume, the air under double the pressure of the atmosphere would have double its ordinary density and only half of its ordinary volume. Under three atmospheres it would be reduced to a third of its volume, under a hundred atmospheres to a hundredth part, and so on. There is no reason to believe that atmospheric air can, by any practicable amount of pressure, be reduced to the fluid or solid state. We might therefore conclude that it will bear without essential alteration any degree of compression, and that this being removed it will return at once to its original volume—and, on the other hand, that it is capable, if all pressure be withdrawn, of dilating to any extent. But recent investigations show that Mariotte's law is strictly correct only within certain limits, and that under extreme pressure the resistance of the atmosphere is disproportionately increased. As to interminable rarefaction, it supposes also a continual production of sensible heat, which is wholly incompatible with what we know of the upper regions of the atmosphere. It is obvious, however, that since the air yields to pressure, gaining in density as it loses in volume, its density must decrease continually from the ground upwards as far as it retains the properties that characterize it at the earth's surface; for the pressure at the ground is that of the entire atmosphere, but as we ascend we shorten the incumbent column of air, which is lighter than the whole, not only because it is but a part of it, but also because its collective density decreases in the same ratio as its length. The atmospheric pressure, therefore, depending jointly on the height and on the density of the incumbent column, both decreasing upwards in the same proportion, varies in the inverse duplicate ratio of the altitude, or, in other terms, decreases as the square of the altitude increases.

Of the pressure of the atmosphere we have obvious proofs. If a glass tube, A B (fig. 62), about 3 feet long and closed at one end, A, be filled with mercury and then inverted with the open end, B, in a basin or other vessel, C, of the same fluid, the mercury in the tube held vertically, will descend a few inches, leaving

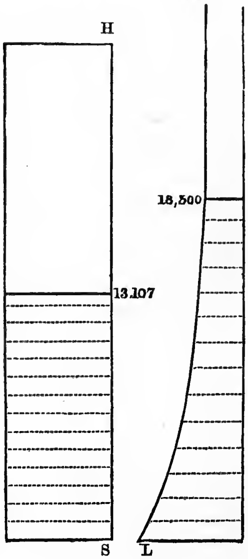
Fig. 62.

a vacuum above to that extent, and will stand at the height of about 30 inches above the surface of the mercury in the basin, being sustained entirely by the pressure of the atmosphere on that surface. The tube thus containing a column of mercury supported under a vacuum of atmospheric pressure, is the barometer in its simplest form. Water may be raised to the height of about 34 feet by withdrawing the air or creating a vacuum above it by means of pistons with valves. This is done more or less perfectly by the ordinary pump. A water-barometer may therefore be made, having about 36 feet length. But the superior weight of mercury allows the length of the instrument to be abridged. Thus it appears that a column of 30 inches of mercury, or of 34 feet of water, weighing 14·7 lbs. on the square inch, is able to counterbalance the whole pressure of the atmosphere. Hence it has been inconsiderately inferred that the human body sustains, without perceiving it, a constant weight of nearly 15 tons. This immense weight, however, exists only in fallacious language. A man supports weight by muscular exertion; but the atmosphere exacts from him nothing of the kind. It does not press him downwards, but compresses his body equally in all directions, from below as well as from above, internally and externally, filling his lungs and giving firmness to the cellular tissue of which he is formed; and this compression is obviously as indispensable for his stability and strength as bone and muscle. A balloon might be, and perhaps has been, made with a surface equal to a thousand times that of the human body; but we should not be justified in saying that such a balloon rising in the air would support a weight of 15,000 tons.

Dry air at the temperature of 60° Fahr. and under a barometric pressure of 30 inches, is lighter than water in the ratio of 1 to 825, and than mercury in that of 1 to 10,513·5. A hundred cubic inches of it weigh 30·935 grains. Hence it is easy to calculate the height of the column of air that would counterbalance

30 inches of mercury; and we find that a column 26,220 feet, or very nearly five miles high, and having throughout the density of the air at the earth's surface, would be exactly equal in weight to the actual atmosphere, which, as it continually decreases in density upwards, must reach an altitude far exceeding that just stated. The hypothetical, or as it is commonly called the homogeneous atmosphere of uniform density may be represented by a column, H S, with parallel sides (fig. 63), and therefore of equal breadth throughout, the breadth of the column representing the density of the air. But the column A L that represents the real atmosphere must be bounded on one side by a hyperbolic curve, constantly approaching the other side, but never meeting it. Thus it might be concluded from the expansibility of the air that the atmosphere has no limit. But it is more probable that the cold consequent on extreme rarefaction deprives it of its elasticity and forbids its further expansion. In the homogeneous atmosphere the pressure of half of the atmosphere would of course be found at half its height, or 13,110 feet (nearly 2½ miles); but in reality the barometer stands at 15 inches at the altitude of 18,500 feet, or a little more than 3½ miles; so that, supposing the whole height of the atmospere to be 35 miles, the lowest tenth of it equals in weight the other nine tenths. Fig. 63 represents the lower half of the atmosphere, divided into parts, each counterbalancing an inch of mercury.

Fig. 63.



Dry air dilated by heat loses density and weight; but its elasticity increases, and its power of occupying space is not diminished. Colder and heavier air may creep in at the base of the heated column; but becoming itself heated in the warm region, it loses the invasive power of superior weight. Consequently a wide extent of heated atmosphere over a dry region does not easily give way to the weightier air that surrounds it. But if it covers water the case is altered ; evaporation takes place, the uprising vapour carries air with it, and an ascending current is established ; the heated air then gives way to the pressure directed towards the ascending current.

Let it be observed that while the mercury in the barometer rises or falls as pressure changes, it also expands or contracts with change of temperature ; thus the effects of atmospheric pressure and of temperature are blended together in the height of the mercurial column ; and if we would conclude from it the amount of the former, we must correct it by subtracting what is due to the influence of the latter. This is done by reducing all observations of the barometer to a common temperature (32° Fahr.)—that is to say, by deducting from the height of the mercury when above, or adding to it when below the freezing-point, the amount of dilatation or contraction respectively due to the difference between the standard and the observed temperatures. Thus, if we would compare an observation of a barometer at 28° with another at 60°, we must add to the mercurial column in the former case the dilatation caused by 4° Fahr., and must deduct in the latter that due to 28° Fahr. The mercurial columns thus corrected represent the effects of atmospheric pressure, and nothing else.

Since the pressure of the atmosphere decreases upwards in a geometrical ratio and may be measured by the barometer, it follows that observations of this instrument made at different elevations (at places not so far asunder as to exclude the supposition that the observations were made under like atmospheric conditions) furnish the means of determining the difference of altitude between those points, and consequently the absolute elevation of one, if that of the other be known. Thus if one observation be made at the level of the sea and the other on the summit of an adjacent mountain, the absolute height of the latter may be determined. For if we suppose the column of air embracing the two points to be divided into strata by equidistant planes, these strata will present a geometrical progression of decreasing pressures, of which we know by observation the first and last terms; and if we know also the ratio of decreasing pressure—say, for example, $\frac{1}{10}$ of an inch (or as 300 to 299, the barometer at the level of the sea being supposed to stand at 30 inches) for 87·5 feet—we may deduce from these data the sum of the strata or the difference of altitude between the two points. Care must be taken to correct the barometers for difference of temperature; and since gravitation above the earth's surface decreases as the square of the distance from the earth's centre increases, a further correction must be made for this inequality.

At the distance of little more than 22,000 miles from the earth's surface, the centrifugal force generated by the rotation of the globe on its axis is equal to its attraction. At that distance, therefore, the atmosphere, if it reached so far, could no longer be retained, but would flow off to be again attracted, it has been suggested, by the moon, sun, or planets. Yet there seems to be some contradiction in supposing that what has escaped from one rotating body can be caught by another. The chief bodies of the solar system, as they all rotate, are all encircled by lines, at which centrifugal force nullifies gravitation. The dissipation, however, and loss of the atmosphere would inevitably ensue were its dilatation unlimited. It is more reasonable, therefore, to suppose, with Dr. Wollaston, that extreme cold deprives it of elasticity and sets a limit to its rarefaction. But to determine on theoretical grounds the distance at which the atmosphere comes to an end is a difficult problem. Plausible calculations assign for its height at the equator and poles respectively 35 and 27½ miles.

The experimental means of solving the problem connected with the height of the atmosphere are extremely scanty. The Arabian astronomer, Alhazen, was the first who watched the last gleams of twilight, in order to calculate from them the height whence the light was reflected to the earth. Proceeding in the same way, Kepler, Delahire, Lambert, and others have assigned to the atmosphere heights varying from 50 to 30 miles. But these attempts, made with inadequate knowledge, to determine its upper limits by observation of reflected light, have generally erred by assuming that the light is seen after a single reflection; whereas light may be often traced in the heavens after several reflections. M. Biot, the disciple and friend of Laplace, concluded, from a long study of the phenomena of twilight, that the greatest height from which light can be reflected by the atmosphere is 43,000 metres, or 26·7 miles; but while thus stating the highest assignable limit, he plainly intimates his belief that the reflection ordinarily takes place much lower down.

But it must not be supposed that the height and pressure of the atmosphere are strictly constant. The ocean of air is rarely free from waves and currents; and consequently the mercurial column in the barometer, affected by this agitation, varies frequently in height, though ordinarily within narrow limits. In the latitude of 51° N., at the level of the sea, and the temperature of 32° Fahr., its mean height is 29·92 inches; at 62° Fahr. 30·012 inches. In Paris, where (in latitude 48° 50′ 13″) there is a slight increase of pressure, its ordinary height is 30·04 English inches, or in French measure 760 millimetres. It is usual, therefore, to assume that the ordinary height of the barometer is in round numbers 30 inches. In these latitudes its fluctuations often extend to half an inch, and occasionally, in very stormy weather, exceed 2 inches. Taken all over the globe, they go to the extent of 3 inches, thus showing a variation, generally transient, of one tenth in the pressure of the atmosphere. The barometer may rise in fine cool weather to 30·5 inches, and it may fall in violent gales to 27·5 inches. When a column of air contracts in cooling and sinks, air flows in upon it from around, so as to preserve the level of the atmosphere. An addition is thus made to the cooled column and its weight is increased. Wherever a deficiency of atmosphere, indicated by a low barometer, exists, an influx of air, that is a wind, rushes towards it. A low barometer, therefore, precedes wind, and continues till, the disturbance being over, the equilibrium of the atmosphere is restored. Hence the barometer is high in calm and cool, low in warm and windy weather.

Since the pressure of the atmosphere depends to some extent on temperature and the quantity of vapour diffused through it, it undergoes periodical variations, connected with the phases of the sun's daily and annual course. The daily variation of the barometer was already detected in the 17th century; but a long course of observation was required to establish precise conclusions. In general the barometer is highest in the morning and evening, lowest at noon and at night or in the early morning. The hours of change vary with place and season; but the mean times are as follows:—

	h	m			h	m	
Morning minimum	3	45	A.M.	Afternoon minimum	4	5	P.M.
„ maximum	9	37	„	Evening maximum	10	11	„

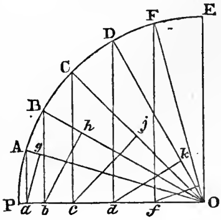
Since the barometric column rises and falls inversely as temperature, it might be naturally concluded that it would be lower by day than by night. But whence comes the double change, the rise in the morning and evening, the fall at noon and after midnight? To explain this, attention must be directed to the two components of the atmosphere, viz. dry air and vapour, both affected by heat, but differently in degree and manner, so that they interfere with and modify each other's action. As the sun's heat increases in the forenoon the air grows lighter, and the vapour, also lighter than air, ascends with a rapid current; the barometer therefore falls, till in the afternoon, the heat abating, the vapour loses its support, the air contracts, and a downward pressure takes place, which reaches its maximum about two hours before midnight. The vapour then falls to the ground, and its weight is withdrawn from the atmosphere. This occasions the morning minimum. But soon after the vapour is again called up, though little rarefied, the air and ground being still cool; and to its ascent is due the morning maximum of the barometer. The hours of the daily barometrical variation change with the season. As the day grows longer, the morning maximum grows later; the afternoon minimum earlier. From the important part played by vapour in these changes, it will be readily understood that where it is deficient, the double daily fluctuation disappears altogether, as at Nertchinsk in Eastern Siberia, and also where it is invariably abundant, in the zone of perpetual rain. The accumulations and vicissitudes of vapour are greater near the earth's surface; and consequently places at great elevations experience its influence only in a modified degree. Thus the summits of the Rigi and Faulhorn in Switzerland, compared with Zurich, those of the Great St. Bernard and the Brocken compared respectively with Geneva and Halle, show a tendency to suppress the double fluctuation and to vary with a single maximum and minimum in the twenty-four hours. But these exceptions to the general rule are observed only on heights adjacent to low country, and not on extensive elevated plains, as those of Bolivia and Mexico.

The daily periods of the barometer are easily observed near the equator, where they are so regular that the time within a few minutes may be learned from the changes, though extremely minute, of that instrument. But in high latitudes they are less plainly marked, and so overlaid with frequent incidental changes, that they can be detected only by the careful study of a long series of observations. In Cumana (lat. 10° 27′ 52″ N.) the daily amplitude is one tenth of an inch, in St. Petersburg hardly a hundredth. Between the tropics it decreases in the rainy season, elsewhere in winter.

The yearly periods of the barometer are everywhere too feebly marked to be easily discerned in the midst of numerous non-periodic changes, and can be learned only from a long series of careful daily observations. Yet attention was called to them by Pascal in 1658. Throughout the greater part of Europe, excepting on high mountains, there are two annual maxima (one in winter, the other at the beginning of autumn) and two minima (in April and November respectively). The two maxima are generally equal, though towards the north and west that of summer predominates; but towards the east and wherever the oceanic climate gives way to the continental, the winter maximum becomes superior. This character begins to show itself in Mecklenburg. Thence eastward and southwards constantly increasing, it extends over Siberia, China, and Northern India, embracing also Syria, Arabia, Abyssinia, and probably a portion of Northern Africa. Throughout this wide and collectively dry area the barometer falls from winter to summer, and much lower than in any other part of the earth. In Europe generally, high mountains excepted, the annual amplitude of the barometer does not exceed two French lines; at Greenwich it is 2·58, at Manchester 2·59. But in Asia the depression from winter to summer amounts at Barnaoul to 7·36, at Yakutsk to 7·81, Udskoi 8·36, Peking 8·72, Canton 5·85, Benares 6·57, Calcutta 6·63. Iceland, on the contrary, shows a barometric maximum in summer ; and this peculiarity is still more strongly marked in Sitka, on the N.W. coast of America. Greenland and the Arctic Archipelago seem to follow the same law. In the Southern hemisphere the atmospheric pressure seems to be less than in the Northern, owing perhaps to the greater amount of vapour, where there is so much ocean to furnish and no land to condense it. In the same hemisphere the Isobaric lines (that is to say, the lines marking equal pressures) are not irregularly contorted as in the Northern, but, being little interfered with by land, lie nearly in the same direction as parallels of latitude.

The atmosphere being from its mobility and position more under the influence of centrifugal force, is more oblate than the solid globe within it, and is therefore much higher at the equator than at the poles ; but its pressure does not correspond with its figure. The heat about the equator, and the ascending current of air in the equatorial zone of rains and calms (to which attention shall be directed further on), counteract in that quarter the effect of its height. Consequently the pressure of the atmosphere is greatest at a distance of 25° or 30° from that zone on both sides. A great accumulation of air over those latitudes is the consequence of the tendency given to the atmosphere by the earth's rotation to flow towards the equator. On the meridian, P E (fig. 64), take the points A, B, C, D, F, dividing the whole quadrant into arcs of 15°, and from these points draw the perpendiculars Aa, Bb, &c. Draw also the rays O A, O B, O C, &c. ; and to these from the points a, b, c, &c. draw the perpendiculars ag, bh, cj, &c. We have thus so many right-angled triangles, O Ff, O Dd, O Cc, &c., in which the rays O F, O D, O C represent gravity, the perpendiculars Ff, Dd, Cc, &c. the rotatory forces. But these latter may be decomposed, Aa into ag and gA, Bb into Bh and hb, Cc into cj, jC, &c., ag, bh, and cj representing those components of the

Fig. 64.



rotatory forces which are horizontal at the points A, B, C, and directed towards the equator; while gA, hB, and jC represent the centrifugal forces at the same points opposed to gravitation and extinguished by it. It is obvious that while the rotatory force varies as the sine of latitude, the horizontal component of that force increases from the pole to lat. 45°, where it attains its maximum (cj), being equal to the centrifugal force, and thence again decreases towards the equator. Hence it is evident that the rotation of the globe tends to heap up the atmosphere between lat. 45° and the equinoctial line. The barometric pressure over and about the equatorial ocean is exhibited in the following Table, drawn from the observations of Captain Beechey:—

Lat. N.	Bar. inches.	Lat. S.	Bar. inches.
0°– 5°	29·895	0°– 5°	29·918
5–10	29·929	5–10	29·971
10–15	29·954	10–15	30·013
15–20	30·005	15–20	30·037
20–25	30·022	20–23	30·040

According to Schouw, the barometer at the equator stands at 29·92 inches, in lat. 30° N. at 30·24, and then declines till in lat. 50° it again comes to 29·92, and in lat. 65°, near the polar circle, sinks to 29°·57. Thence to the pole it is thought to rise; but this is doubtful. At a distance from the tropical zone the barometer is inconstant, and a greater number of observations than have yet been collected are required to determine the variations of its mean height along a meridian.

An aeronaut of great experience (Mr. Green) informs us that the barometer, when it stands on the ground at 30 inches, will fall at the height of

1 mile to	25 inches.	
2 „	21 „	
3 „	17 „	
3½ „ (18,480 ft.)	15 „	
4 „	below 14 „	(13·9).

This, though not precise, cannot be far from the truth.

A. Schlagintweit, on the Himâlaya, found the barometer to stand at 15 inches (indicating half the weight of the atmosphere) at an elevation somewhere between 18,600 and 18,800 feet. At the height of 22,200 feet, according to the same traveller, it stood at 13·364 inches, about $\frac{9}{20}$ of the atmosphere being still above it.

CHAPTER IX.

Water—its Composition—its Metamorphoses and change of State.—Dilatation and Contraction.—Specific Gravity.—Wonderful Transformations.—Aqueous Vapour.—Table of Evaporation—its Conditions.—Tension of Vapour.—Saturation—how Measured.—Humidity unequally distributed over the Globe.

WATER is the protoxide of hydrogen, or the product of oxygen and hydrogen chemically combined in the proportion of one volume of the former to two of the latter. The weight of a volume of atmospheric air being taken as the unit of measure, that of an equal volume of oxygen will be 1·1057, and that of hydrogen, the lightest body known, 0·0692. Estimated in weight, therefore, 8 parts of oxygen and 1 of hydrogen make 9 of water. But the water thus produced equals in volume little more than the 2000th (strictly the 1964th) part of the gases producing it. The union of the gases is effected by their combustion in a close vessel. Mixed together in due proportion, they may be kindled by an electric spark. The same two gases which unite to form water will, when made to issue from a single jet in like proportions, viz. two volumes of hydrogen and one of oxygen, burn in the air with the most intense heat. Platinum, pipeclay, and other substances which resist the heat of the strongest furnace, melt at once in the heat of the oxy-hydrogen blowpipe. In this case, oxygen, being supplied by the atmosphere also, is in excess, and the gases are wholly consumed. At 60° Fahr. the weight of water is 816 times that of air. Distilled or perfectly pure water at the temperature of its greatest density (39°·34 Fahr. or 4° C.) furnishes the unit of density of all bodies ; its specific gravity therefore is 1.

Water changes its state and becomes fluid, solid, or gaseous with comparatively moderate changes of temperature and pressure. It dilates with increase of temperature from 39°·34 Fahr., expanding at the rate of about one 612th part of its volume for every degree of the Fahrenheit scale. Under the ordinary barometric pressure (30 inches) it boils at 212° Fahr., though its ebullition may be retarded a little by the nature of the vessel employed. When made to boil, it vaporizes not merely from the surface, but from the bottom and throughout, the ebullition being caused by the discharge of the steam into which the water is converted. The position of the boiling-point depends on the combined heat and pressure. It would rise to 240° if the atmospheric pressure were doubled, and it would fall to 67° if that pressure were altogether removed.

As water dilates when heated, so it contracts in cooling, till at 39°·34, or nearly 7½ above the freezing-point, if fresh and pure, it attains its greatest condensation. This temperature is a natural constant of great importance, fixing, as already stated, the standard unit of density of fluids. Below as above that point water dilates at a uniform rate; so that at the temperature of 36° Fahr. it has the same volume as at 42°·68 Fahr.

With increasing cold it continues to dilate, till at a temperature generally a little below 32° Fahr. it congeals or becomes solid. In undergoing this change 142 degrees of heat are apparently wrung from it, being really produced by the force of contraction; and the same amount of heat must be afterwards expended on the ice to make it melt. Water seldom freezes immediately at the temperature of 32°, or the freezing-point as it is called. It may, when perfectly still, be cooled down to 20° (or even, it is said, to 5°) without congelation; but the slightest vibration suffices in this state to cover it with a pellicle of ice. In the act of congelation it gives out heat and fixes at the temperature of 32° Fahr., at the same time undergoing a sudden expansion far exceeding that incidental to the fluid state. The force with which this expansion takes place is enormous. Strong iron shells filled with water and carefully closed are burst and scattered in fragments by the freezing of their contents. It has been calculated that the force exerted in the act of freezing by a ball of ice one inch in diameter is equal to the pressure of 22,000 lbs. But it seems probable that the expansive force of congelation is equal to the compressing force necessary to melt ice; and it has been found that ice may be melted instantaneously by a pressure equal to 13,000 atmospheres, or 190,000 lbs. on the square inch. The water of ice thus forcibly and quickly melted, has a temperature of −4° or 36° below the freezing-point.

The specific gravity of ice, under the ordinary atmospheric pressure, is 0·916, that of water at the temperature of the greatest density being 1. Consequently ice is lighter than water, and floats in it with nearly a tenth of its volume above the surface. Water is believed to be in some degree compressible, and to yield to the extent of about 51 millionths, or a little more than one 20,000th part of its volume for every atmosphere added to the pressure. At the depth, therefore, of 34,000 feet, or nearly 6½ miles, the water of the ocean deep, supporting a pressure of 1000 atmospheres, would lose by compression a twentieth of its volume.

It follows, from the manner in which water is affected by temperature, that when it becomes cooled at the surface and thereby condensed, it must sink and give way to warmer, less condensed, and therefore lighter fluid. Thus a vertical circulation takes place, the cooled water sinking and the warmer rising, till by the continuation of the process the temperature of greatest density, or 39°·34, has been established throughout, and this done, the circulation ceases. The water at the surface being then no longer heavier than the water beneath it, has no inclination to sink, but remains to congeal and float as ice. Thus the entire congelation and conversion into ice of a deep body of water is rendered so difficult as to be in fact almost impossible. For the preliminary condition, the cooling of the whole body of water requires much time, more perhaps than a single winter; and when a crust of ice has been formed on the surface, circulation beneath it being at an end, external cold can penetrate but a little way. All the local ice of a hard winter disappears in spring in a few days.

Among all the wonders of nature, there is nothing so wonderful in all respects as water. It takes many forms, and in all serves the most important purposes. We learn with astonishment that charcoal and the diamond are the same in substance, though so unlike in appearance. But how much more astonishing is it that water should be formed of the same two gases which in like proportions feed the fiercest flames. Water takes the solid state to check the progress of cold ; as a fluid, it covers three fourths of the globe, and forms the great highway of nations ; as vapour, it floats or flies in the clouds, and scatters its benefits over the earth. It is the general solvent. There is no life without it. The vegetable world is nourished entirely by watery solutions ; and every plant consists to a great extent of water. It enters in like manner into the bodily structure of animals, and forms nearly four fifths of human blood.

While water dilates with increasing heat, it also manifests its loss of cohesion by increased evaporation, or the escape of its particles from the surface in the form of vapour. This change rapidly advances with heat, till at the temperature of 212° or the boiling-point, the formation of vapour ceases to be confined to the surface. Large volumes of vapour, at the highest temperature (and in this condition called steam), then rise from the bottom of the vessel (where the heat is greatest), and, shooting up violently, throw the water into that turbulent agitation called ebullition, or boiling. Ebullition exhibits in the most energetic manner the conversion of water into vapour ; but for this purpose compulsion is not absolutely necessary. The evaporation of water takes place at all temperatures ; even the coldest ice gives off some vapour ; and the rapid wasting of snow during a hard frost can hardly escape observation. Water, in fact, is always disposed to imbibe heat and go off in the gaseous form. The three volumes of gas combined in water, viz. one of oxygen and two of hydrogen, form two volumes of aqueous vapour, which, as a transparent gas, is lighter than atmospheric air in the proportion of 625 to 1000. In undergoing this change, each particle of water absorbs as much heat as would suffice to raise the temperature of 960 such particles one degree Fahr. In truth aqueous vapour is a temporary reserve of heat, and might perhaps be as justly deemed a form of heat as of water. Hence it is obvious that evaporation is a cooling process, since it is attended with great abstraction of heat from the surrounding medium. Increase of temperature, wherever water is present, is sure to be followed by a still greater increase of evaporation. The presence of water, therefore, tends to moderate heat. In order to follow aqueous vapour through the whole course of its circulation, it will be necessary to consider it under the heads of evaporation, tension, saturation, and precipitation, which last, as being the extinction of vapour, and concluding its history, shall be treated of further on.

We cannot tell of evaporation, any more than of temperature, where it begins. The air may be comparatively dry, but it is never quite free from vapour. Ice at the lowest temperature still evaporates and wears away, as does snow also, without visibly melting. Excessive cold, while repressing vapour, at the same time renders it more manifest by condensing it into fog. The frost rime of polar latitudes is a dense fog, produced by a cold, dry wind, which sweeping over the warmer ice or open sea takes from it some humidity. This, often rising but 10 or 20 feet above the surface, is condensed and frozen, so that the effect is the same as if a cloud of fine snow-dust were raised from the surface of the sea.

The nature of evaporation was first set in its true light by Dalton, who showed that the quantity of vapour diffusible through the atmosphere at any one time depends wholly on temperature. Evaporation may be checked or retarded by the pressure of air or gas of any kind ; but, leaving out of the account the slight effects of varying atmospheric pressure, its ultimate amount is regulated by temperature alone. He ascertained that from a surface 6 inches in diameter, under dry air, the weight of vapour carried off in 24 hours, at different temperatures, is as follows :—

Temp.	grain.	Temp.	grains.
20° F.	0·52	55° F.	1·77
25	·62	60	2·10
30	·74	65	2·46
32	·80	70	2·88
35	·90	75	3·40
40	1·05	80	4·00
45	1·26	85	4·68
50	1·50	212	120

Evaporation proceeding from the exposed surface of the fluid or humid body, is abundant in proportion as the surface is ample. Less vapour rises, therefore, from a smooth sheet of water than from curling waves and broken spray. Rough ground when moist, as it generally is in winter, gives off more vapour than an equal area of water. Vegetation still further divides the liquid particles and multiplies the evaporating surface. In general it doubles the evaporation. Dew-drops scattered over a meadow fly off in vapour in less than half the time that would be required to dissipate them if collected in one sheet of water. If vapour be not quickly carried off as it rises from the ground, the process of evaporation is thereby checked. Wind, on the other hand, increases its activity. Since the quantity of vapour which may remain suspended in the air depends wholly on temperature, the activity of evaporation at any moment is regulated :—1st, by its tension ; 2ndly, by the amount of humidity already diffused through the atmosphere ; and, 3rdly, by the circulation. No addition of vapour can be made in an atmosphere already saturated. But if there be little approach to saturation, if the atmospheric pressure be light and the space for diffusion unlimited, as at great altitudes on mountains or in balloons, then the air will appear extremely dry, and rapid evaporation will take place even at low temperatures.

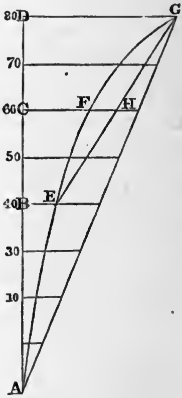
If a little water be introduced from below into the tube of a barometer, it will rise at once to the surface of the mercury, and there finding a vacuum, will vaporize. The mercury will consequently fall, since the elastic force of the vapour in the place of the vacuum counteracts more or less the weight of the atmosphere that supports the mercurial column. The depression of the mercury measures the tension of the vapour or its power of occupying space, the connexion of which with temperature may be thus perfectly ascertained, as will be seen in the following brief extract from Dalton's Table of the Tension of Aqueous vapour :—

Temp.	Tension, in inches of mercury.	Temp.	Tension, in inches of mercury.
32°	0·200	100°	1·860
40	·263	120	3·330
50	·375	140	5·740
60	·524	160	9·450
70	·721	180	15·150
80	1·000	200	23·640
90	1·360	212	30·000

From this Table it will be seen that, owing to the continual addition of new vapour, vapour-tension increases much faster than temperature. Steam cut off from its supplies becomes instantly powerless. It is also worthy of remark that what is commonly called the latent heat of high-pressure steam diminishes with increase of temperature. Steam at 400° imparts no more heat to water than would be communicated by the same volume of steam at 212°. This is the necessary consequence of the pressure under which steam is raised to high temperatures; and this may be ascribed jointly to accession of heat, and to the compression reacting on increased tension and converting latent into sensible heat.

The fact that the increase of vapour-tension is more rapid than that of temperature, has an important consequence which deserves attention. If temperature and its accompanying humidity always varied in the same proportion, then in all mixtures of currents at different temperatures the same harmonious proportions would still be found. But since the increase of vapour outruns that of temperature, the air formed by the mixture of any two vapour-laden currents of air will always be supersaturated; for their united vapour exceeds the amount supportable by their mean temperature (fig. 65). This admits of easy illustration. Suppose that A B and A D on the same vertical right line represent the temperatures of two currents of air, while B E and D G (drawn perpendicular to that line) respectively denote the vapour-tensions of A B and A D. Now, if these currents be mixed together, C H, halfway between B E and D G, will mark their mean amount of moisture, which exceeds C F, the vapour-tension of their mean temperature. The mixture therefore is supersaturated.

Fig. 65.



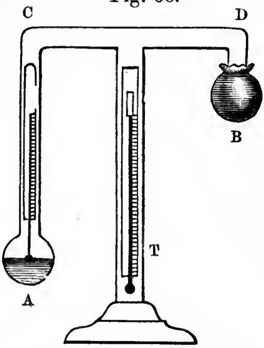
But to return to the experiment with the barometer; the higher the temperature the greater will be the tension of the vapour, and the consequent depression of the mercurial column; and if the heat and supply of water be sufficient to fill the tube with vapour at 212°, this vapour will totally expel the mercury, its tension then exercising a force equal to the pressure of the atmosphere. So far vapour, being supported by a supply of heat, comports itself like a gas; but tried by pressure, it is compelled to lay aside this assumed character. Air confined in a tube resists compression by its elasticity; it yields only in proportion as the compressing force is increased, and when the latter is withdrawn recovers at once its former volume. Bearing in the first instance the pressure of the atmosphere, it requires the additional weight of a second atmosphere, or of 30 inches of mercury, to reduce it to half its volume, and the weight of four atmospheres to reduce it to one fourth. Vapour, on the other hand, has no inherent invincible elasticity. It has enough for existence under favourable circumstances, but nothing to spare, and offers no resistance to pressure. If in the experiment with the barometer above described the mercury in the tube be increased, each drop added will cause the condensation of a portion of the vapour, which is thus, by the least excess of pressure over its tension, reduced to the fluid state. The highest tension attainable at any given temperature is called the state of saturation; and in that state any increase of pressure or any fall of temperature is immediately followed by condensation of vapour. But if the tension (through deficiency of water or other causes) be below the point of complete saturation, then the temperature may fall without condensing the vapour, till it meets that point; for it is obvious that saturation draws nigh as temperature declines. And here it is necessary to remark that the word saturation is most commonly made use of by meteorologists in a totally incorrect sense; for when they speak of the observed saturation of the atmosphere at any time, they mean only the approach to saturation measured in degrees or the quantity of vapour present in it estimated in proportion to the quantity permitted by temperature (or to total saturation).

Thus it is evident that with the aid of Dalton's Table we can at any time determine from the temperature how great may be the tension of the atmospheric vapour. The atmosphere, however, is rarely in a state of complete saturation; and it is desirable to know not merely the possible but also the actual tension of the vapour contained in it, and the difference between them. Now, we have seen that, where the vapour-tension is below saturation, we can nevertheless make it suffice for saturation by lowering the temperature. If we cool the air till its vapour condenses, and note the temperature at which the deposition takes place, then, knowing the natural temperature of the air and that obtained by cooling, we can learn from Dalton's Tables both the possible and the actual quantity of vapour contained in the air, and can express the latter as a fraction of the former.

Dew is deposited as often as the cold of night leads to saturation, and the atmospheric vapour falls condensed. This process is easily imitated. While cooling the air gradually, we must observe the temperature at which the condensation of vapour first takes place; and thence, with the aid of the Tables, we learn the actual tension of the vapour. Suppose we have two thermometers exactly alike in form and capacity, one of them having its bulb covered with muslin, wetted with ether, the other remaining dry. Now the evaporation of the ether produces cold; the mercury in the wet-bulb thermometer, therefore, sinks, and just as it reaches 50°, for example, vapour begins to condense on the glass. At the same time the temperature of the air, as shown by the dry-bulb thermometer, is 80°. But from the Tables we learn that the possible tension at 80° is 1, while the actual tension, being that at 50°, is only 0·375. The ratio of this number to unit is that of 37·5 to 100; the saturation, therefore, is said to be 37·5 per cent.; that is to say, the vapour in the air amounts to 37·5 per cent. of that which would completely saturate it at the temperature of 80°. Again, suppose the dry-bulb to mark 77°, while the dew-point on the wet-bulb is found to be 59°. Now the tension corresponding to the latter indication is 0·196, while that possible, or marking complete saturation at 77°, is 0·923; we therefore conclude that as 0·923 is to 0·196, so is 100 to $\frac{19600}{923}$, or 21 per cent. of saturation.

The two thermometers are often combined in one instrument, called the wet-bulb thermometer, and thus constructed. A wide glass tube (A C D B, fig. 66) is bent at right angles, so that while the middle portion of it, C D, remains horizontal, two arms

Fig. 66.



terminating in bulbs, and of unequal length, C A and D B, hang down vertically. The bulb of the longer arm, A, is half filled with ether, into which dips a small thermometer enclosed in the tube. The bulb of the shorter, B, is covered with muslin moistened with ether. The cold produced by the evaporation of this condenses the vapour of the ether within the tube, and quickens its evaporation. Moisture then condenses on the lower bulb, A, containing the ether; and the temperature at which this takes place may at the same instant be learned from the small thermometer dipped in the ether and compared with the indication of the thermometer, T, externally affixed to the instrument.

At sea the wet-bulb thermometer is generally but 6°·3 below the dry-bulb thermometer, indicating an approach to saturation of about 80 per cent. But as the boiling-point of sea-water (218°·6) is 6°·6 above that of fresh water, it is likely that the elasticity of vapour from salt water is at all temperatures below that of fresh water, and that the air over the ocean has all the saturation derivable from that source. It is obvious that, supposing the quantity of vapour in the atmosphere to remain constant, the saturation will be more complete the lower the temperature. It is in winter, therefore, and in cold latitudes that mists and cloudy weather are most frequent. The sensations by which we distinguish between moist and dry climates are due wholly to the degree of saturation, and not to the quantity of vapour actually present in the atmosphere. In Devonshire or the West of Ireland the air often feels clammy; every thing attracts moisture and becomes mouldy. In North America, where high temperature and humidity generally go together, the stranger wonders at the dryness of the air, at the slowness of decomposition, and the ease with which meat may be preserved. Houses may be seen built in Armenia of salt, on the shores of the Red Sea of trona (carbonate of soda). Now, in all these cases of dry climate the tension of vapour, or the proportion of it in the atmosphere, may be greater than in Ireland; but it bears a much less proportion to complete saturation, the point of which is raised by temperature.

In a thick mist, the air being saturated, the two thermometers, the dry and the moist, would agree in their indications. But in the dry Siberian Steppes, between the rivers Irtysh and Obe, M. von Humboldt found them to show a difference of 50°·4 Fahr.; and near Arkiko, on the Abyssinian shores of the Red Sea, M. Ant. d'Abbadie observed a difference of 40° Fahr. At Benares has been observed in July a tension of 1·038 inch, fully equal to a 29th part of the whole atmospheric pressure. At Nertchinsk, in Eastern Siberia, 2200 feet above the sea, the tension in January is barely the $\frac{1}{250}$ of an inch. Decreasing towards the poles, from the equator, where it sometimes amounts to $\frac{1}{27}$ of the whole pressure, the mean annual vapour-tension varies in Europe from two fifths (0·41) of an inch at Naples, to one fifth (0·22) in Northern Germany, whence it diminishes towards the east, till at Tiflis (Armenia) it is only $\frac{3}{20}$ (0·15) of an inch.

Evaporation and atmospheric humidity decrease from the equator to the pole, but with an irregularity that shows to what an extent the influence of latitude is counteracted by local circumstances of position. This will be evident from the following brief Table, in which the annual amount of evaporation given in inches of water decreases generally with the increase of the distance northwards from the equinoctial line; while yet westerly position and proximity to the ocean, or to mountains that arrest the rain-bearing winds, often cause a violation of the rule, and give the more northern position the more copious moisture:—

	Lat.			Lat.	
Cumana	10° 27′ N.,	138	Breslau	51° 7′ N.,	15·5
Rome	41 54	77·8	London	51 30	25·1
Marseille	43 18	90·6	Breda	51 35	25
Bordeaux	44 50	63	Rotterdam	51 55	24·8
Augsburg	48 21	64	Liverpool	53 25	37·6
Manheim	49 29	72·8	Manchester	53 29	44·2

The humidity of the atmosphere is not only more abundant at the equator, but it also there attains a greater altitude than elsewhere. Vapour-tension, however, diminishes upwards, though (owing to currents and still more to the clouds, which latter are concomitants of high saturation) not with regularity. Mr. Glaisher in his ascent in a balloon from Wolverhampton met with what he deemed perfect dryness at an elevation of about 16,000 feet. Yet proof that humidity can be collected and float at an elevation of five or six miles, may be often seen in fine cirrous clouds high above the Andes and other lofty mountains. Atmospheric humidity, as expressed by the tension of vapour, diminishes also as the distance from its source increases. Hence places far inland or leewards have in general a comparatively dry atmosphere.

CHAPTER X.

Temperature—of the Atmosphere.—Mean Temperature—how found.—Lamont's Table.—Meech's Table—its defects.—Radical Imperfection of Tables of Temperature.—Insolation regular, its effects irregular.—Dry Air diathermanous.—Glaisher's Table of Atmospheric Temperature.—Effect of Clouds.

The sensible effects of heat vary, as already stated, according to the capacity for heat of the body on which it falls. The greater that capacity, or the specific heat of the body, the greater will be the measure of heat required to raise it to a given temperature, and therefore the lower will be its temperature acquired from a given measure of heat. Consequently the same amount of solar heat calls forth very different temperatures, according as it is expended on land, sea, or air. A sunbeam falling on the ground is almost wholly arrested at the surface: it penetrates but a little way—the daily vicissitudes of heat being barely felt in our latitudes at a depth of 4 feet, the annual perhaps at a depth of 40. Consequently the naked ground exposed to the sun's rays often grows intolerably hot. In hot tropical countries, such as the dry deserts of Africa, Australia, and the shores of the Red Sea, the thermometer in contact with the ground has been known to rise to 140° Fahr., or even to 158° Fahr. This excessive heat of the ground stimulates the ascent and circulation of the air above it, so that the atmospheric temperature still remains comparatively moderate. The sea, on the other hand, is penetrable by heat as well as light to a considerable depth, 60 fathoms at least, but perhaps much further; and water has the greatest capacity for heat. Consequently, in every zone of the earth, the portion covered by water is that which varies least in temperature.

Between the extreme fluctuations of the land with respect to temperature and the comparative constancy of the ocean, the air holds a middle place; and since it envelops every thing on the earth's surface, while it ministers to animal and vegetable life, its temperature is most important; and therefore, when countries or places are compared with respect to temperature, it is the temperature of the air that is intended. But the air being subject to every influence from sea or land that can act on a very mobile and susceptible medium, varies unceasingly, and no single observation can determine its daily temperature. If the thermometer were observed every 5 minutes during 24 hours, and the sum of these results were divided by 288, the number of observations, the quotient might be justly considered as expressing the mean temperature of the day. But experience proves that the same end may be attained with sufficient accuracy, and much more conveniently, by taking the mean of observations made at selected hours, morning and evening, as for example, at 4 and 10 o'clock A.M. and P.M., or at 6 A.M., 2 and 10 P.M.; or at 7 A.M., noon, and 10 P.M. Some are satisfied by assuming the temperature at 9 o'clock A.M. to represent the mean temperature of the day, while others prefer to observe the maximum and minimum temperatures, and take half their sum.

The time of the daily minimum is generally supposed to be at sunrise; while some make it precede sunrise by an hour or more. In reality, however, it varies with the season and state of the heavens, preceding sunrise in cold and clear weather, and coinciding with or even following it in warm weather with much vapour.

The hour of maximum heat follows noon later as the day grows longer, or as the quantity of heat received in the forenoon increases. In Geneva (lat. 46° 12′) the greatest heat of the day occurs in winter at $1^h\ 53^m$; in summer at $2^h\ 57^m$; in Leith (lat. 55° 58′ 54″) the daily maximum in midsummer is at $3^h\ 27^m$. On the Great St. Bernard the time of the daily maximum varies in the course of the year from $0^h\ 40^m$ to $1^h\ 15^m$, showing that at a great elevation and in a rare atmosphere the influence of the direct heat from the sun is less interfered with by that radiated from the ground. The difference between the greatest and least temperatures, or the extent of the fluctuation of temperature in the course of a day, month, or year, is called its amplitude, daily, monthly, or yearly, and is a most important characteristic of climate. Two places having the same mean temperature, but with different amplitudes, will have very different climates.

The mean temperature of the month is found by dividing the sum of the mean temperatures of the days included in it by the number of the latter. Thus, if all the daily mean temperatures in October amount, in Rome, to 2009°·42, we have only to divide that sum by 31, and the quotient 64°·82 will be the mean temperature of the month. That of the year may be derived in a similar manner from the mean of the months. If in Rome these added together amount to 726°·84, then the twelfth of this sum, or 60°·57, will be the mean yearly temperature of that city. The daily means form the foundation of accurate meteorology; but science cannot dispense with generalizations; particulars have little value if they do not lead to comprehensive conclusions.

The monthly means clearly show how temperature varies with change of season; but they conceal to a great extent the annual amplitude, or the extremes of heat and cold, experienced in different parts of the earth during the year. From Tables of monthly mean temperature it might be concluded that the greatest difference between the cold of the polar regions and the heat of the torrid zone is only about 140°. But there is good ground for believing that it occasionally far exceeds that amount. The greatest cold or annual minimum of heat on the European continent generally occurs about the 14th of January. After that date the increase of heat goes on slowly till April or May, when it grows rapid, the greatest heat being felt about the 26th July. The mean temperature of the year occurs twice, viz. on the 26th April and 21st October. These, however, being mean dates, are but approximately true, and do not exclude local differences of a few days. At Rome, owing to the snows of the Alps and the prevalence of north winds that retard the spring, the mean temperature of the year falls on the 1st May, and the greatest heat on 1st August. Moderation and stability of temperature bespeak the influence of the ocean; great amplitude of temperature or alternate excess of heat and cold characterize the predominance of land. Such is the contrast between the oceanic and continental climates.

The decline of solar heat with increase of latitude holds out such promise of regularity as induced the celebrated Edmund

Halley and other eminent philosophers to compute Tables of climate founded almost wholly on that consideration. A brief extract from one of the most elaborate of these Tables will enable the reader to understand its scope, and the waste of labour involved in it :—

Mean Monthy Temperatures, according to M. Lamont.

Lat.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean of the year.
0°	70°·7	72°·1	73°·7	73°·9	73°·2	70°·8	70°·7	69°·8	70°·8	72°·1	72°·1	70°·7	71°·9
15	63·5	65·3	67·5	70·7	72·5	72·1	72·8	71·6	71·	69·9	67·8	64·4	69·1
30	52·6	53·4	56·5	60·7	65·3	68·9	70·7	69·3	66·9	62·5	58·1	54·4	61·6
45	37·2	38·1	42·2	48·5	54·8	59·	62·5	61·5	57·1	51·	44·7	39·5	49·7
60	18·5	19·8	24·8	32·6	40·6	47·	49·8	48·5	42·5	35·7	27·7	22·4	34·2
70	5·6	6·8	12·4	21·7	29·5	36·3	39·3	38·1	31·4	24·3	15·5	8·6	22·5

The writers who thus thought to tabulate the climates of the whole globe, all proceeded on the assumption that from the insolation or amount of solar heat poured on any point in the meridian may be deduced its mean temperature, regardless of aerial currents, and apparently forgetting that there may be, and generally is, a great difference between the heat emitted and that received, and also that, in the absence of the sun, an antagonistic power, terrestrial radiation, is incessantly at work, so that the result sought is really compounded of two opposite forces, and depends much on the prevalence of clouds or clear skies, which are very unequally distributed over the earth. The absence of the sun implies not merely the privation of his heating rays, but also exposure to the intense cold of the serene heavens. But the failure of these attempts to construct a generally applicable theory of terrestrial heat will be best learned from a close examination of Mr. Meech's "Table of the Intensity of Solar Heat," which, being drawn up with minute care and of recent date, seems to be regarded by many as a conclusive authority.

Mr. Meech having shown how the sun's rays are weakened by oblique incidence on the earth's surface, concludes that solar heat is at every point on a meridian proportional to the cosine of latitude, and adopts as a perfect expression of it Sir David

Brewster's formula T=80°·5 cos. lat., T being the temperature of the place, and 81°·5 the mean temperature of the equator. He omits to consider the loss of heat by oblique incidence in its passage through the atmosphere, by which it is reduced probably in the duplicate ratio of the cosine. Then, taking the mean equatorial day as a unit of measure, he calculates the duration of sunlight at every fifth parallel in terms of this unit ; and proportional to these results he proceeds to find parts of equatorial temperature. His own words are, "Taking the annual intensity at the equator as 81°·5, the intensity in other latitudes may be expressed in that proportion." In short, he concludes that as 365·24 solar days at the equator are to the number of such days at L (any latitude), so is 81°·5 to the mean temperature of L. Thus has been formed the following Table :—

Yearly Insolation.

Latitude.	Equatorial days.	Meam temp.
°		°
0	365·24	81·5
5	363·97	81·22
10	360·19	80·38
15	353·91	78·97
20	345·21	77·03
25	334·20	74·57
30	321	71·63
35	305·70	68·21
40	288·65	64·39
45	269·79	60·20
50	249·74	55·73
55	228·82	51·06
60	207·76	46·36
65	187·85	41·92
70	173·04	38·61
75	163·22	36·42
80	156·63	34·95
85	152·83	34·10
90	151·59	33·83

In this Table the first thing that calls for remark is, that the formula T=81°·5 cos. lat. excludes from consideration the effect of the atmosphere on the transmission of heat; yet at the pole four fifths at least of the solar heat must be intercepted by the atmosphere. Mr. Meech, indeed, candidly confesses that his adopted formula "is strictly true only outside of the atmosphere." This might be taken as an admission that his Table is not applicable to the surface of the earth. But in truth he never meant to admit so much. He gave little attention to the defect intimated, nor has he pointed it out so expressly as to prevent its misleading others. He could not, indeed, with consistency be so candid; for his reasoning is based on an assumption of a contrary character—since 81°·5, the assumed mean temperature of the equator, is not only not true "outside of the atmosphere," but, falling considerably below the summer heat of the tropics, obviously exemplifies in the clearest manner the effect of interposed atmosphere, active evaporation, and constant clouds in abating the central heat of the torrid zone. But since the figures at the head of the third column in Mr. Meech's Table denote mean temperature at the surface, an incautious reader might naturally suppose that the following figures deduced from them belonged to the same category, and are true "inside of the atmophere." His incidental remark, that "the laws of terrestrial temperature," as distinguished from the intensity of solar heat, which he has investigated, "will require a special and apparently a more difficult analysis," allows us to hope that, while the latter branch of knowledge remains imperfectly developed, he will not expect us to accept in its stead a series of theoretical deductions widely at variance with experience.

Mr. Meech tells us that "during the summer season, or for 85 days from the 10th May to the 3rd August, the sun's intensity at the pole is one fourth greater than at the equator. Indeed at the summer solstice it rises to 98·6 thermal units, corresponding nearly to 98° Fahr." As Dr. E. Schmid, in his valuable 'Lehrbuch der Meteorologie,' repeats this account of the superior heat of the polar summer, he must be supposed to have overlooked the following explanatory sentence:—"The measured intensity refers to the upper limits of the atmosphere, upon which the sun shines continually, but from a low altitude which cannot exceed

23° 27″." This is fairly stated; but, on the other hand, the comparison of the sun's imaginary intensity at the pole, from a low altitude and *above the atmosphere,* with the real intensity at the equator below a thick screen of clouds, is calculated to mislead. The mean heat received at the pole from the sun between the horizon and the altitude of 23° 27″ cannot exceed 12°·25. Where Mr. Meech's figures come nearest to the truth (in middle latitudes), they are certainly not applicable to every meridian; and Tables only partially applicable are useless. He underrates the heat of the equatorial zone, and he much overrates that of the polar regions. Captain Scoresby informs us that in the polar seas the sun's heat may melt the pitch on one side of a ship while on the other side the sea is freezing. The ship's side, coated with a material well disposed to absorb heat, is nearly perpendicular to the sun's rays, which, from a low altitude, impart no heat to the surface of the ground or to the air. The temperature in those regions cannot possibly rise above the freezing-point till the ice and snow are all melted, a work which occupies most of the summer. According to Dr. Kane, there rises in that season a thick fog, which never clears away; the sun is often invisible for some days, and from noon till midnight there is but little light. Our information respecting the polar regions is excellent and abundant; and it does not allow us to assign to the pole a higher mean temperature than +2° Fahr., or nearly 32° less than that found for it by Mr. Meech. And yet its temperature, though still low, has been raised probably many degrees by extraneous causes above that due to its position with respect to the sun.

To Mr. Meech's Table of terrestrial temperature, and all others of the same kind, there lies one objection which deserves to be attentively considered. However completely may be ascertained the measure of heat incident on different parts of the earth, it seems impossible to derive from that knowledge any formula that will give the mean temperature of a place in terms of its latitude, because such a formula implies the power of finding proportional parts of heat. But it is manifestly impossible to divide proportionally that of which we know neither the beginning nor the end.

The thermometer is partial and relative; it does not tell the absolute quantity of heat, but only serves to compare temperatures within a limited range; the degrees of its scale are not proportional parts of heat. Several formulæ have been proposed to connect mean temperature with latitude; but to show their futility it will suffice to examine the simplest of them, that of Sir D. Brewster, adopted by Mr. Meech. If it be true that the mean temperature of any place is equal to the mean temperature of the equator, reduced in the ratio of radius to the cosine of that place's latitude, then we ought to have the same result whatever be the thermometric scale employed. Now, assuming 81°·5 to be the mean temperature at the equator, since the cosine of lat. 60° is half of radius, the mean temperature of that latitude, according to Brewster's formula, is 40°·75. But in the Centigrade scale the temperature of the equator is 27° 5, and that of 60° lat. therefore 13°·75, which latter is equal to 56°·75 Fahr., a result differing from the former by 16° or half the difference between the zeros of the scales. These results, therefore, cannot be both true; but on what grounds can we prefer one to the other? The zero of the scale being an arbitrary point, the same formula tried with different scales gives totally different results; and if all scales had the same zero, their harmony would be delusive; for their starting-point would be still arbitrary, and could not claim to be the beginning of heat.

It might be thought that since insolation depends chiefly on the sun's altitude and the length of the day, the amount of it received along any parallel of latitude, where these two conditions remain constant, would be everywhere the same. But such is not the case. Though equal heat fall on all parts of a line, it may not meet in all parts with a like reception. According as it falls on sea or land, on lofty mountains or low plain, on arid rock or on vegetation, on clouds or through clear atmosphere, the share of it that meets the surface and is given back to the lower atmosphere varies within wide limits. If it anywhere accumulates, it is carried off by winds or currents from one latitude to another, so as to complicate the irregularities due to local causes.

In order to illustrate the irregularity above spoken of, we shall here exhibit for comparison, in a brief Table, the mean temperatures for the winter, the summer, and the year, of a few groups of places in (or nearly in) the same parallels of latitude, but in three different tracts of longitude, viz. along the western coasts of Europe bordering on the North Atlantic Ocean, from north to south over North America, and, lastly, over Eastern Asia.

	Lat.	Long.	Winter.	Summer.	Year.	Ampl.
Northumberland Sound	76° 52′	− 97° 0′ W.	−35°	33°·4	−0°·5	68°·4
Melville Island	74 47	−110 48 W.	−32·2	37·1	−0·4	69·3
Mageröe	71 10	26 1	23·7	43·7	32·2	20
Ust Yansk	70 55	138 24	−34·3	46·6	3	80·9
Boothia Felix	69 59	− 92 1 W.	−27·6	38	3·7	65·6
Ft. Confidence	66 54	−118 49 W.	−22·9	48·2	12·3	71·1
Yakutsk	62 2	129 14	−37·8	58	11·6	95·8
Bergen	60 24	5 18	36·3	58·5	46·8	22·2
Ft. Churchill	59 2	− 93 10 W.	−14	51·5	17·4	65·5
Aberdeen	57 9	− 2 5 W.	39	59·4	49·1	20·4
Nain	57 10	− 61 5 W.	− 0·4	47	25·1	47·4
Sitkha	57 3	−135 18 W.	33·8	54·5	43·4	20·7
Ajan	56 27	78 18	− 1·7	51·3	25·5	49·6
Belfast	54 37	− 5 58 W.	41·3	63·9	52	21·6
Illuluk	53 52	−160 25 W.	32	47·9	38·7	15·9
Cumberland House	53 37	−102 17 W.	− 3·7	59·9	25·7	63·6
Irkutsk	52 17	104 11	10	61·4	31·1	51·4
Greenwich	51 29	0 0	37·6	60·3	48·8	22·7
Werchne Udinsk	51 49	107 44	− 2·2	65	32	67·2
Rochelle	46 9	1 10	39·4	67·3	52·3	27·9
Quebec	46 49	− 71 16 W.	12·5	69·1	41·9	56·6
Bordeaux	44 5	− 0 35 W.	43	71·1	57	28·1
Toronto	43 39	− 79 21 W.	25·1	63·9	44·1	38·8
Lisbon	38 42	− 9 9 W.	52·4	70·9	61·4	18·5
Philadelphia	39 57	− 75 10 W.	29·1	71·3	51·1	42·2
Pekin	39 54	116 26	26·6	81	54·7	54·4
Funchal	32 38	19 19	69	79	74·9	10
Natchez	31 34	− 91 28 W.	52·2	81	67·1	28·8
New Orleans	29 57	90 0	56·9	82·1	69·8	25·2

The preceding Table makes it sufficiently evident that the coasts of Western Europe in high latitudes enjoy a very remarkable moderation of temperature, while excess of heat or cold, or of both, characterizes the same parallels on the American and Asiatic continents. In Spitzbergen the summer temperature often rises to 44°, or more; 58° has been recorded; the snow on the mountains disappears to a height exceeding 4000 feet. The winter temperature is probably not below 5°. But in Northumberland Sound and Melville Island, some degrees more south, the temperature of summer little exceeds the freezing-point of water, 32°; the cold of winter nearly sinks to that of freezing mercury, – 40°. Hammerfest, at the northern extremity of Norway, is a comfortable town of fishermen and merchants, with a good harbour never frozen up; while Ust-Yansk in Siberia, in nearly the same latitude, built on perpetual ice, endures extreme and persistent cold, and Boothia Felix, in North America, a degree further south, is a desolate land, icebound eight months of the year. Reykiavik in Iceland, with an annual mean temperature of nearly 40° Fahr., is in a higher latitude than Yakutsk, where mercury often remains frozen for three months together. It is worth while to compare attentively the climate of Yakutsk with that of Bergen in Norway, on a parallel only two degrees further south. Observe the wide difference between the climates of western and eastern coasts: Bergen is on the western shore of Europe; Ajan, in a lower latitude, on the Bay of Ochotsk, at the eastern side of Asia. It is worth while also to compare Sitkha, on the western coast of North America, with Nain, on the same parallel in Labrador; and let both be compared with Aberdeen. Again, Belfast, compared with Illuluk in Alyaska, illustrates the superior temperature of the Northern Atlantic. Rochelle has a warmer climate than Quebec, in the same latitude; Bordeaux has, in like manner, the advantage over Toronto. Lisbon enjoys a delicious equability of temperature unknown in Philadelphia and Pekin, in nearly the same latitude. Let it be observed that the continental climate beyond the tropics is invariably characterized by the severity of winter and great range of temperature. Thus Yakutsk, with a summer 5° warmer than that of Reykiavik in Iceland, has a winter 67° colder, and a recorded annual amplitude of 95°·8. But this, being deduced from monthly mean temperatures, falls far short of the actual amplitude that occasionally occurs, and which can hardly be less than 120°. As we approach the equator the annual amplitude everywhere diminishes, and temperature becomes more equable.

Atmospheric air, free from vapour, is almost perfectly diathermanous and intercepts but little of the luminous solar heat. On the other hand, it readily absorbs the obscure heat radiated from the ground, its absorbing-power being greatly increased by the presence of vapour. It serves therefore to prevent the escape of the heat which has passed downwards through it. The sun's rays are allowed to pass undiminished to the ground; but their heat, when radiated from it, is absorbed; consequently the atmosphere receives its heat immediately, not from above, but from below. The air near the ground, dilated by the heat, becomes specifically lighter, and ascends till it reaches a stratum of equal density, in which it becomes laterally diffused, the ascending stream being replaced below by a descending influx of cooler and denser air. Thus any increase of temperature on the earth's surface tends to set the atmosphere in motion, the diffusion of heat disturbing its equilibrium, which is chiefly adjusted by vertical circulation.

Since the atmosphere derives its heat immediately from the earth's surface, it follows that the higher we ascend and the further from the ground, the lower in general will be the temperature of the air. It diminishes in ascending for two reasons:—first, because the immediate source of its heat is further off; and secondly, because as the air grows rarer the loss of heat that accompanies dilatation increases. The rate at which atmospheric temperature falls with increasing altitude is not easily ascertained. From observations made on mountains no satisfactory conclusions can in this case be drawn, since, however high above the level of the sea, they are still on the ground and liable to be affected by its radiation. Those made in balloons were, till very recently, too few to afford sufficient grounds for induction, considering the variety and fluctuating character of the phenomena whose laws are sought for, and hitherto they have been made only in a part of the earth characterized by variability. The rate at which temperature decreases upwards depends much on its condition near the ground and the state of the sky. The greater the heat the more rapid is the rate of its decrease caused by distance. A low degree of heat dies off by a comparatively slow and uniform diminution. Consequently the increase of height required to lower the temperature of the air by 1° Fahr.

is less in bright sunshine than under a cloudy sky, and generally it is less the lower the absolute height.

To the courage and scientific perseverance of Mr. Glaisher meteorology owes its best materials for a well-founded and correct theory of the atmosphere. From that gentleman's abundant observations has been formed the following Table, which will serve to show the increase of altitude experimentally found to lower the thermometer 1° Fahr., under clear and cloudy skies, for every 1000 feet from the ground to the height of 30,000. Irregularity in phenomena may be in general ascribed to disturbance of fundamental laws. In order to exhibit results having natural regularity and free from disturbance, Mr. Glaisher has added a column (the fourth) of corrected observations; and in order to show the principle of this correction, the series of regularly decreasing differences also is here added :—

				Sky cloudy.	Clear sky.		
From		feet.	Depression.	feet.	feet.		
the ground	up to	1000	1° F. for	222	139	139	
1000	,,	2000	,,	239	160	160	21
2000	,,	3000	,,	264	176	181	21
3000	,,	4000	,,	271	195	198	17
4000	,,	5000	,,	323	211	213	15
5000	,,	6000	,,	357	230	226	13
6000	,,	7000	,,	357	243	238	12
7000	,,	8000	,,	370	254	249	11
8000	,,	9000	,,	384	263	259	10
9000	,,	10,000	,,	384	272	269	10
10,000	,,	11,000	,,	384	279	279	10
11,000	,,	12,000	,,	384	286	288	9
12,000	,,	13,000	,,	400	293	297	9
13,000	,,	14,000	,,	455	300	306	9
14,000	,,	15,000	,,	477	308	315	9
15,000	,,	16,000	,,	477	314	324	9
16,000	,,	17,000	,,	527	322	332	8
17,000	,,	18,000	,,	556	330	340	8
18,000	,,	19,000	,,	556	337	348	8
19,000	,,	20,000	,,	667	346	356	8
20,000	,,	21,000	,,	771	355	364	8

			Sky cloudy.		Clear sky.		
From		feet.	Depression.	feet.	feet.		
20,000	up to	21,000	1° F. for	771	355	364	8
21,000	,,	22,000	,,	771	358	372	8
22,000	,,	23,000	,,	1000	368	380	8
23,000	,,	24,000	,,	771	377	388	7
24,000	,,	25,000	,,	909	386	395	7
25,000	,,	26,000	,,	1000	396	402	7
26,000	,,	27,000	,,	1000	404	409	7
27,000	,,	28,000	,,	1111	413	416	7
28,000	,,	29,000	,,	1250	423	423	5
29,000	,,	30,000	,,		428	428	

Irregular distribution of heat in the atmosphere generally attends clouds. On a cloudy day there is often little or no decrease of temperature up to the cloud-region ; but with many strata of clouds variations of the thermometer become frequent. Hence Mr. Glaisher chose for correction, as a more regular basis, his series of observations made under a clear sky ; and the results thus obtained may be taken to represent, without any material error, the normal decrease of temperature upwards when that on the ground is moderate (about 65°). The irregularities arising from interfering currents in the atmosphere were found by him to be frequent and striking. On one occasion he left the ground with a temperature of 59°, which at 1000 feet fell to 26° ; but at 13,000 feet the thermometer began to rise, and at the altitude of 19,500 feet marked 42°. Six or seven thousand feet higher it fell to 16°. The disturbance characterizing the cloud-region, and ordinarily occurring at a height of from 5000 to 9000 feet, sometimes extends far beyond those limits. Mr. Glaisher, on one occasion, entered the clouds at the height of 1500 feet, and continued to pass through strata of clouds till he reached 23,000, and even there he had not reached the limit of vapour. Yet it is obvious that interrupted decrease of temperature with increasing altitude must be ascribed to accidental causes, and that the elimination of their influence alone can enable us to approximate to the true law of that decrease.

The same indefatigable meteorologist has still more carefully studied the distribution of heat in the lower region of the atmosphere, or up to 5000 feet. Under a clouded sky, temperature up to the clouds is very uniform ; with a partially covered sky it declines

	feet.	per 100 ft.		feet.
for the first	100,	0°·9 F.,	making for 1° F. an ascent of	110
from 100 to	300,	0·8	„	125
300 to	500,	0·7	„	143
500 to	900,	0·6	„	166
900 to	1800,	0·5	„	200
1800 to	2900,	0·4	„	250
2900 to	5000,	0·3	„	333

"With a clear sky," he tells us, "the greatest change is near the earth, 1° for less than 100 feet, till at 5000 feet the decrease is 1° for 300 feet ;" and it is evident that the higher the temperature on the ground the more rapid is its decrease in ascending.

CHAPTER XI.

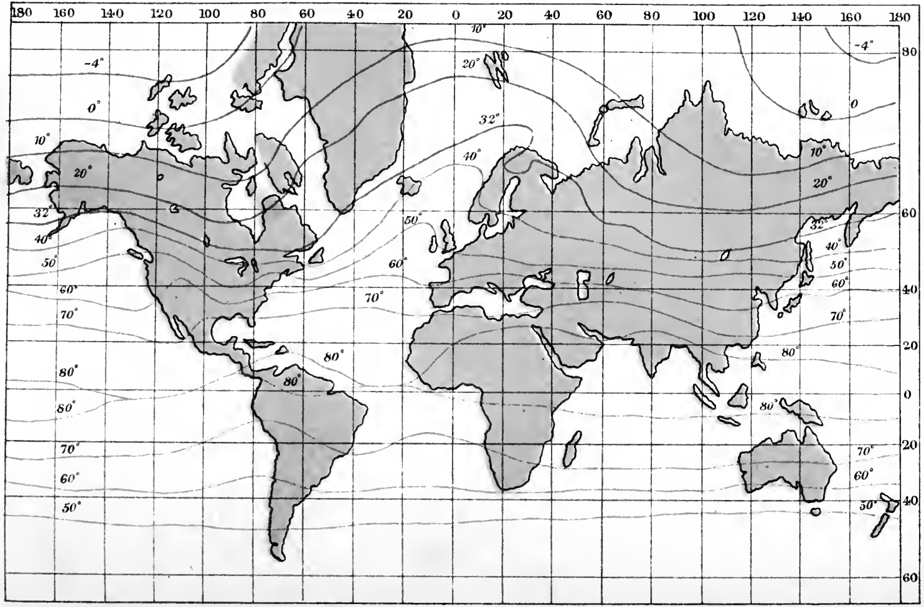
Lines of equal Temperature—Hypsometrical.—Isothermals at the Level of the Sea.—Thermal Equator—its Position and Oscillation.—Line of Freezing Temperature traced in October—in January—its Position in July.—Isotherms in the Southern Hemisphere.—Influences of Sea and Land.—Abnormal Temperature of Western Europe—not due to predominance of Land—its true Cause.—Unequal Polar Seas.—Isobars, their relation to Isotherms.

The sources of heat having been treated of, as well as the various modifications to which it is liable from the constitution of the ground or atmosphere, it now remains to consider how temperature is actually distributed over the earth's surface. It is manifest that it is not regulated merely by position on the globe, and that two places on the same parallel of latitude may differ widely in climate—such irregularity in distribution of temperature not being accidental or transient, like inconstancies of weather, but to a certain degree fixed and permanent. Recourse must then be had to observation to determine the lines which mark equal temperatures at the level of the sea, and the deviation of which from the parallels of latitude may in every case, when viewed comprehensively, be explained from surrounding circumstances.

If we follow a parallel of latitude for some distance on land, we are sure of finding on it sooner or later a change of temperature; and if we persist in tracking the temperature we began with, we must of course quit the parallel, deviating from it either towards the pole or the equator. The line thus marking a grade of mean temperature on the earth's surface is called an Isotherm (from the Greek ἴσος, equal, and θερμὸς, hot). In order that Isotherms may be strictly comparable, they ought to be made at, or by correction reduced to, the same altitude, viz. the level of the sea; for change of temperature may be found not merely by going from the equator towards the pole or in the contrary direction, along the horizontal plane, but also by change of place in the vertical plane.

In ascending one of the snowy summits of the Himalaya or

PLATE 6.



MEAN ANNUAL ISOTHERMAL LINES.

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Andes, we should pass in succession through all the temperatures found between the equatorial regions and the poles. Thus we may suppose the earth invested with a number of isothermal planes of spheroidal figure, rising at the equator one above the other, and towards the poles successively meeting the level of the sea—the whole system oscillating in the direction of the meridian with the sun's declination, and manifesting, at the limits of the planes or the isothermal lines of the earth's surface, irregularities which we propose to study. Thus on the side of Antisana, in the Andes, we find at the elevation of 12,624 feet the isothermal plane of 41° Fahr., which in January meets the sea-level in the Northern hemisphere a little to the north of Montpellier and Bordeaux, but in May passes through the summit of the Brocken to reach the surface near Torneo and Archangel, and in July meets the sea-level at the middle of Spitzbergen. The isothermal plane which following the sun's declination advances towards the north pole, recedes at the same time from the south pole. The heights in the atmosphere which separate the successive thermal planes cannot be assigned with precision. For moderate heights the decrease of temperature may be taken to be one degree for every 276 feet of elevation; but at great heights the rate diminishes to a degree for 330 feet.

Thus isotherms traced by experience render manifest by their deviation from parallels of latitude, which are strictly symmetrical, the irregular distribution of heat on the earth's surface. From the position and course of isothermal lines, marking mean temperatures, drawn on a map of the world (see Plate 6), it will be seen :—

1st. That the line of greatest heat, called by some the thermal equator, is not coincident with the equinoctial line, but lies for the most part to the north of it ; and also that it is not constantly a single line, but at certain times and places returns upon itself so as to enclose a space of higher temperature, which is merely local and does not go round the earth.

2nd. The isotherms about the poles are not disposed so as to form circular areas, but rather irregular compressed ellipses, as if they tended to arrange themselves round two poles of cold, one in North America, the other in Eastern Siberia.

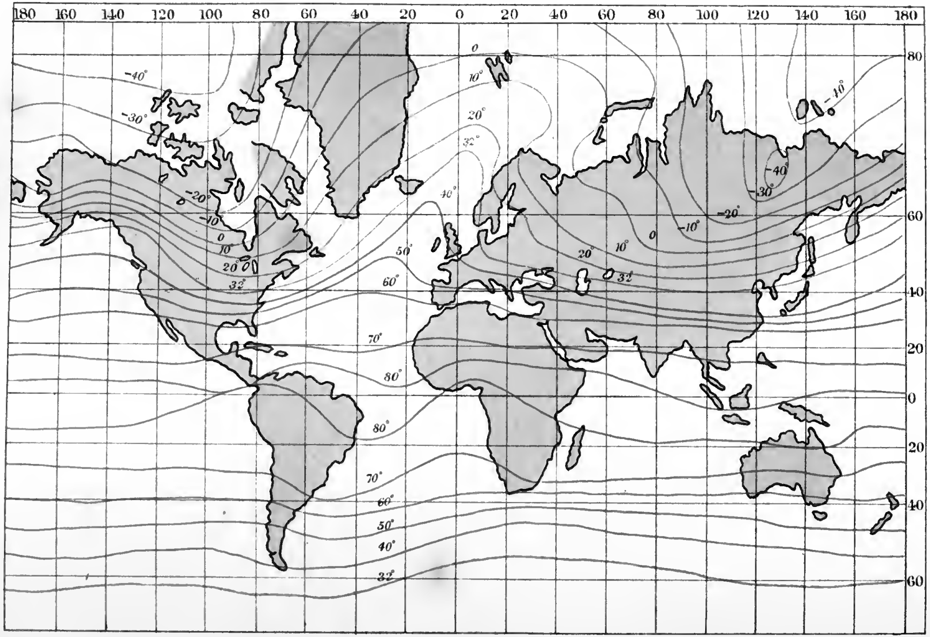
Fig. 67.

Isotherms of the North Pole for January.

Fig. 68.

Isotherms for July.

PLATE 4.



ISOTHERMAL LINES FOR JANUARY.

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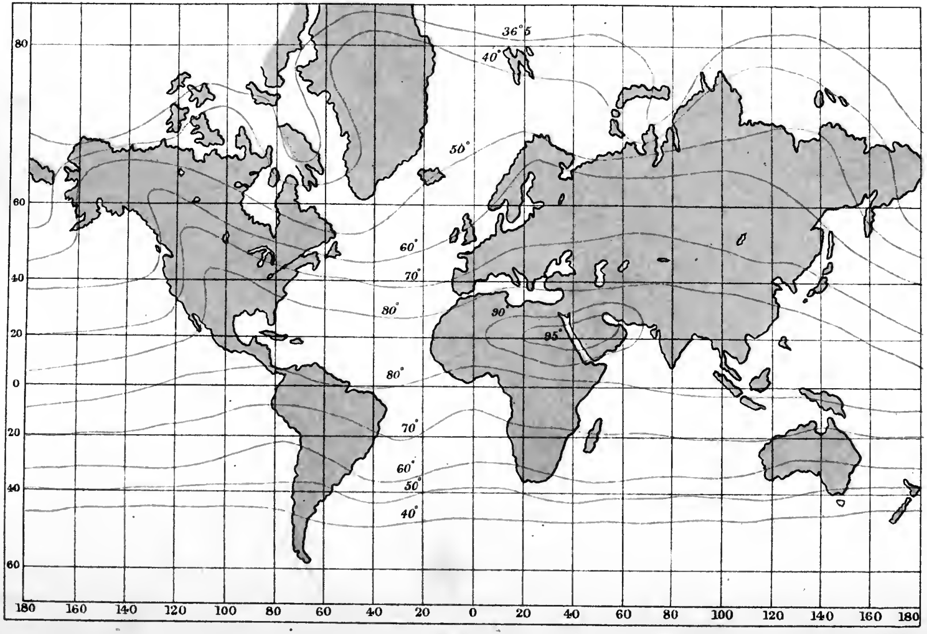
PLATE 5.



ISOTHERMAL LINES FOR JULY.

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3rd. They are comparatively regular in the southern hemisphere, where the ocean predominates; and attain their greatest irregularity in the temperate and cold regions of the northern hemisphere, where they pass from sea to land, and cross great continents.

4th. Isotherms, following to some extent the sun's movement in declination, change their position and figure with the seasons; and therefore by means of isotherms of the months we may learn the gradual changes of heat in the earth throughout the year. The isotherms of summer and winter will show the mean limits of temperature in those seasons (Plates 4 & 5). Those of the north-polar summer are given in fig. 68.

The amplitude (or extent of variation) of the thermometer at any place is an element of so much importance in the estimate of its climate, that particular attention is due to the isotherms of summer and winter, respectively entitled Isotheres and Isocheimones, though these do not give the absolute extremes of temperature (which occur perhaps only once or twice in a year), but the average extremes of three months. When the temperatures of the whole earth in all seasons, as marked out by isotherms, are fully considered, it becomes evident that some regions have more, some less heat than is due to their position in respect of the heavens. These regions may be separated in the map by lines joining places with equal excess or defect of temperature. The lines of this new series are called Isanomals (of equal irregularity). With the actual distribution of temperature over the earth thus depicted on a map before our eyes, the irregularity of the isotherms being contrasted with the regularity of the parallels of latitude, and illustrated by the outlines of sea and land, we have no difficulty in detecting, on the face of the earth itself, the cause of the diversion of heat into particular channels, and of its unequal distribution over the globe.

Isothermal lines at the sea-level are ordinarily double; that is to say, isothermal planes intersect the sea-level at both sides of the equator, and lines marking the same temperature go round the earth in both hemispheres. But as the sun approaches the tropics, the extreme temperatures of the remoter pole disappear altogether from that which is nearer to the sun, and the hemispheres lose their thermal symmetry. About the equator a high temperature is sometimes developed in spots marked by lines which do not go round the earth, but form irregular rings; or the isothermal line will sometimes divide and form a loop embracing a temperature higher than any found elsewhere in the same zone. Let it be observed that when isotherms on the map recede from the equator, they carry a given temperature nearer to the pole, and show an increased warmth of climate; when they bend towards the equator, a decline of temperature is to be thence inferred. Hence it follows that if two isotherms lying one on each side of the equator, have parallel deviations, they indicate a fall of temperature on one side, and a rise on the other. When they lie close together, they show a rapid change of temperature at right angles to their course.

Since isotherms oscillate with the sun, they will reach their extreme positions in midwinter and midsummer, and their greatest amplitudes (or differences) of deviation will be found by comparing the isothermal lines of January with those of July. Their mean position follows the equinoxes at a little distance; and as the autumnal equinox is little liable to disturbance, the isotherms of October may be regarded as nearly representing the mean temperature of the earth. In attempting to lay down the isotherms on a map of the world, the first step must be to endeavour to fix the position of the thermal equator or central line of greatest heat. There is, however, no continuous undivided line of highest temperature traceable round the earth, though there is a zone of greatest heat. This zone, with a temperature of 80° to 81°·5, never in the new world moves far from Yucatan or Central America. In summer it dilates so as to embrace within it all the islands and encircling coasts of the West-Indian seas, Florida and Venezuela included. On the continents of Africa and Asia it expands considerably as heat increases; so that in July it embraces the southern shores of the Mediterranean Sea, and encloses an area of much higher temperature, a tract extending from Central Africa across the Red Sea to the eastern side of the Persian Gulf, having a mean temperature of 90°·5. It is then collectively far north of the equator. In January it contracts, or perhaps disappears, in the Eastern Pacific for a distance of 12 degrees, where the cold south-polar current flows that bears the name of Humboldt. It then lies rather south of the equator, its greatest breadth being in the meridians of New Guinea and Australia.

The isothermal lines drawn on the earth between the regions of extreme heat and cold deviate so frequently and so much from regular symmetrical courses, that a minute verbal description of them would probably be tedious rather than satisfactory. They may be most advantageously studied in Dove's plates of the "Monthly Isothermal Curves." Here it will be sufficient to call attention to those salient features of the isotherms which suggest at once the natural causes to which all their modifications may be traced; so that the space saved from descriptive details may be devoted to explanation.

In October, when the temperature of the earth is not far from its mean state, the isotherm of 32° Fahr., or the freezing-point, is found at Behring's Straits just above the polar circle (lat. 66° 33′ N.). Thence it runs south-eastward over the American continent to long. 120° W.; having crossed the Rocky Mountains, it takes a more easterly course over the southern portion of Hudson's Bay, and reaches the coast of Labrador, near Nain, in lat. 56° N., having thus moved 10° 33′ southwards in its passage over the land. There, at the sea, it turns north-eastward, and, cutting across the southern extremity of Greenland, holds its course along the eastern coast of that country to the polar sea till it approaches a point three or four degrees to the north of North Cape, or to lat. 74° N., carrying the same temperature from Labrador 18° further north. It there bends back in a very extraordinary manner, running south-westwards along the coast of Norway, till near the polar circle it turns inland, and resuming its eastward course, passes near Torneo and Archangel; on entering the vast Asiatic continent it again leans to the south-east, and sinks near Nertchinsk to lat. 51° N. Thence, as it approaches the sea, it turns north-eastwards to the polar circle and Behring's Straits. The fall of temperature towards the east thus indicated proceeds rapidly on the lee side of Scandinavia, where the sea-winds and vapours of the Atlantic are no longer felt.

At the same date the isotherm of 50° Fahr. is met with on the western coast of North America in lat. 51° N., immediately above Vancouver Island. Entering the continent from the west, it turns southwards till it has passed the Rocky Mountains, when it takes an eastward course till it reaches the Atlantic Ocean. Here, owing to the warmth of the ocean, it turns to the north-east, touches the 60th parallel of north latitude at the Shetland Islands, and then, winding round to the west of south, traverses Scotland and the eastern side of Ireland, from which, in lat. 52°, it goes off eastwards. In this direction it crosses England, bends on the continent of Europe a little towards the south-east, till in the plains of Hungary it reaches the 46th parallel of latitude. It thence goes nearly due east till, beyond the Caspian Sea, it again inclines to the south and approaches the 40th parallel in the neighbourhood of Pekin ; a little further on, having reached the ocean, it inclines to the north-east till it regains the latitude of 51° N. It is evident that the Shetland Islands owe it to the influence of the ocean that they have in October as high a temperature as Pekin.

In January the isotherm of 32° holds a course parallel to that just described, but in general about 15° further south, the cold descending southward about 1350 miles. It includes Vancouver Island, sinks in the interior of the American continent below the 40th parallel, and quits it to the south of New York. Then running north-eastwards over the ocean to the 70th parallel, it bends southwards, grazing the coast of Norway near Bergen, passes south of Vienna, sinks in the interior of Asia to the 39th parallel, then, going south of Pekin to the ocean, bends a little to the north-east, and crosses the northern end of Nipon. The isotherms of lower temperatures are arranged (nearer to the pole) in courses generally parallel to that just described, but with one striking irregularity ; for after bending round south-westwards at the Scandinavian peninsula, and then turning eastwards, they make a second bend southwards on approaching or entering Siberia, so as to make way for that elongated tract of intense cold uniting North America with the eastern part of the old world, already pointed out.

In July, when the heat of the northern hemisphere has reached its maximum, the form and position of the described isotherms are completely changed. The isotherm of 32° retires altogether from the well-known portions of the earth. That of 50°, leaving the polar circle at Behring's Straits, runs E.S.E. across the American continent to Nain on the coast of Labrador, thence goes north-east to Iceland, rises as it passes over the Scandinavian peninsula, sinks a little to the south of Novaya Zemlya, then rises again as it runs parallel to the coast of Siberia, till in long. 165° E. it suddenly bends southwards, and, entering the ocean to the east of Kamchatka, does not resume its eastward course till it meets the 42nd parallel. The isotherm of 59° leaves lat. 40° N. in the middle of the Pacific Ocean, rises towards the north-west coast of America, there turns northwards, till in lat. 65° it wheels round and runs east by south across the continent, reaching the Atlantic just to the south of Newfoundland. It then turns north-eastward and eastward through Edinburgh, bends more to the north in crossing Scandinavia, then a little to the south in the meridian of Novaya Zemlya, then again to the north, passing near Ustyansk in lat. 70° N., and then drops southwards into the Sea of Okhotsk. The isotherm of 77° is found at lat. 20° N. in the middle of the Pacific, rises gradually towards the coast of America, nearly reaches the 40th parallel in the middle of that continent, then falls about 20 degrees in the Atlantic, rises again on approaching land, passes through the northern half of the Mediterranean Sea, attains its greatest elevation (44°) at the eastern side of the Caspian Sea, and then sinks at a uniform rate by land and sea till it again rejoins the 20th parallel.

The isothermal lines of the Southern hemisphere may be described with much more brevity, yet sufficiently for our purpose. The isotherm of 77° Fahr. is found in October in the middle of the Pacific Ocean, near the 18th parallel of south latitude. It thence goes E.N.E. beyond the equator towards Central America, turns east-south-eastwards across the continent, so as to meet the Atlantic in lat. 16° S.; over the sea it again runs towards the equator, again bends to the E.S.E. across Africa, and beyond Madagascar resumes its course in the 18th parallel. The isotherms marking lower temperatures all bend in the same manner E.N.E. on the eastern side of the Pacific and in the

Atlantic Ocean, and E.S.E. over the American and African continents—but in a continually less degree, till that of 50°, passing through Patagonia and New Zealand, differs in October little from a straight line. In January, the summer of the southern hemisphere, it becomes more incurvated. Cold currents from the South Polar Ocean lower the temperature of the Pacific and Atlantic oceans along the western coasts of South America and Africa. Hence the isotherms over those currents bend towards the equator; but on crossing the land they return to a more southern track.

The isotherms of the southern hemisphere run generally east and west with little irregularity. There is no land so situate on the globe as to intercept an equatorial current and compel it to flow southwards into high latitudes. But if Africa were united by a neck of land with Kerguelen Island (in lat. 49°), the latter, now named also the Land of Desolation, would assuredly owe to the warm currents flowing round it a climate resembling that of the south of France.

In the isotherms just described it is easy to perceive the influences respectively exercised on temperature by land and sea. The former, susceptible of the extremes of heat and cold, varies much from summer to winter, while the temperature of the sea undergoes comparatively little change. In winter the isotherms across the Atlantic, in the northern hemisphere, turn north-eastwards from the American coast, or recede from the equator, showing an increased warmth of climate over the ocean; but in summer the isotherms from Tropical America run south-eastwards towards the equator, proving that the ocean is then cooler than the land. The isotherms from the Atlantic when they enter on the continents of Europe and Asia, incline towards the south-east or north-east, according as winter or summer temperature prevails over the land.

But this alternation of ocean and continent affords only a vague explanation of the curved courses taken by the isotherms. To explain them in detail, it will be necessary to consider the effects of winds, currents, and other circumstances. When a wind affects climate by its warmth or humidity, it is obvious that the lines marking the degrees or the limit of its operation, must lie at right angles to its direction. Hence it is not surprising that when a cold land-wind blows off the coast of Norway to the warmer ocean, the isotherm passing over this ocean, checked in its course, should wheel round and descend for some distance along the coast, or that, crossing the mountains of Norway at a warmer season, it should turn southwards for some distance at the lee side of them (where the sea-wind is no longer felt), or that, on the confines of Northern Siberia, probably the extreme limit of oceanic westerly winds, it should run for a considerable distance from north to south.

It must be remembered that the isothermal lines drawn over the whole globe are founded on comparatively few observations. If a temperature frequently observed at sea be found on adjacent land much further south, the isotherm joining these two observations and running through different latitudes, rests more on inference than observation. It probably marks a line of very inconstant temperature and perpetually changing winds.

The most remarkable example of abnormal climate presents itself in Western Europe, which enjoys at all times a higher temperature than would belong to it, were temperature the same all round the earth for the same season and latitude. Nor can this advantage possessed by one portion of the globe be reasonably ascribed to the great extent of the continent with which it is connected and to the heat thereby accumulated ; for there is no reason for believing that dry land has any power of accumulating heat, or that it does not part with heat as readily as it receives it. The collective temperature of the earth in July or the northern summer (59°·9) is greater than in January or the southern summer (56°·5), because, we are told, the extent of land in the northern hemisphere greatly increases its summer temperature. But surely it lowers in an equal degree its winter temperature ; and the comparison apparently instituted between the summers of the two hemispheres involves also that of their winters. The frequent reference made to the predominance of land in the northern hemisphere as the cause of its superior mean temperature must surely be erroneous. Siberia is as remarkable for its intense cold as Western Europe is for its exemption from such rigour. In Yemen (the hottest part of the earth) the better class of the inhabitants wear furs in winter, and the cold is frequently intense at a moderate elevation. Wherever, therefore, the northern hemisphere appears to have a permanent superiority in temperature we must look for the explanation of this phenomenon, not to the predominance of land, which could only cause fluctuation within wide limits, but in some disturbance of the balance between sunshine and radiation, such as would arise from abundant vapour.

The advantages enjoyed in respect of mean temperature by the northern hemisphere, and more especially by Western Europe, seem wholly traceable to two causes, viz.:—1st, the great disparity between the north and south polar seas considered as centres whence cold is diffused throughout the ocean ; and, 2nd, the figure of the Atlantic and Pacific oceans, of the former particularly, which arrests the equatorial current and compels it to circulate in the northern hemisphere.

The North Polar Sea may be described as a circular basin, 36 degrees in diameter, hemmed in by land on three fourths of its circumference, and sending ice to the ocean only through Davis's Straits and a narrow inshore tract of the Greenland Sea. The South Polar Sea, on the other hand, is wholly unconfined and spreads its ice-fields over a circle 100 degrees in diameter. Its cold currents are felt on the coasts of Chili and Peru, and in the Atlantic, though they are probably for the most part deep-seated and little apparent at the surface. It can hardly be doubted, then, that the equatorial ocean receives its chief accession of cold water from the south, the consequence of which is that the line of maximum oceanic temperature is pressed northwards. The temperature of the Atlantic, at a depth of 400 or 500 feet below the surface, is, according to Lenz, greatest about the northern tropic, and thence sinks rapidly towards the equator, so that while in lat. 23° N. the thermometer marks 76°·3 at the surface, and 69°·4 at a depth of 80 fathoms, in lat. 3° it marks 83°·5 at the surface, and at a depth of 80 fathoms 58°, the temperature found at the same depth in lat. 40°.

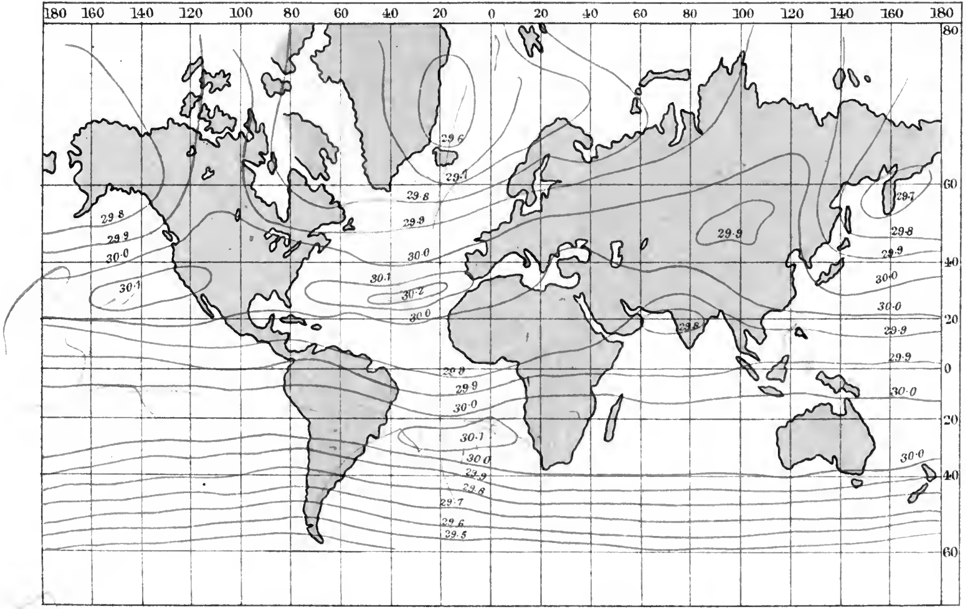
The prevalent doctrine that the high temperature of the northern Atlantic is due to the land encompassing it, compels us to reason in a vicious circle ; for it makes the heat of the land at once the cause and the effect of torrid climate. Thus we read in Sir John Herschel's 'Meteorology', p. 61 :—"In the Atlantic the disturbing influence of the continents is very sensibly felt. The great mass of Africa, and especially of its sandy and burning deserts, lies considerably north of the equator. These become intensely heated ; and their temperature follows the sun much more closely than that of the sea. There can be no doubt that the medial line of the trades crosses Africa considerably to the north of the equator, and that the annual oscillation of the northern trades at least is very great, and the influence extends to the neighbouring Atlantic."

How, then, is this influence of the land extended to the ocean? Is it by contact or conduction? Impossible ; and the isothermal lines show us that during the summer the Atlantic Ocean is colder on its eastern side or towards the coast of Africa than on the west. Is it then by means of the winds? Surely not. If winds like the trades be generated on the African continent, they never reach the sea. There are no trade-winds near the coast of Africa ; but sea-breezes, or as some call them monsoons, blow directly on the shore ; and when the sun is near the Northern Tropic, the aspiration of the African continent is so strong as to check the force of the trade-winds nearly across the Atlantic. The heat of the Old World attains its maximum at the eastern side of Africa, Arabia being its centre, and diminishes towards the west; and it can hardly be supposed to be propagated in the direction in which it decreases. The burning deserts of Northern Africa lie under the Tropic, their southern limit being in about lat. 17° N., while the median line of the trade-winds has its mean position in lat. 7° N., oscillating through only 3 or 4 degrees while the sun goes through 47°.

On the distribution of temperature over the globe depends the variable weight of the atmosphere, which is rarefied by heat and condensed by cold ; its weight therefore at any part changes with seasons, shifting periodically from one hemisphere to the other, and in a still greater degree from sea to land and from land to sea. The changes that take place in the weight of the atmosphere give birth to the winds ; and these carry the sea-born rains to their destination. Thus the chief phenomena of climate hang together in intimate sequence, but so complicated by conditions of accidental character, that to follow them in connected detail within moderate limits would be quite impossible. But the student of Physical Geography ought to keep constantly in view the relationship existing between the thermometer, the barometer, and the rain-gauge, and to study their mutual influence.

A glance at the Isobarometric lines (or lines of equal atmospheric pressure as measured by the barometer) for the mean of the year (Plate 3) discovers at once that the atmosphere is lightest at the poles, being heavier, however, at the northern than at the southern pole. It lies heaviest on the ocean, and especially on the North Atlantic; and the position of the maximum weight outside of the tropics, points evidently to the action of centrifugal force. The depression about the equator is as clearly attributable to the ascending current in the zone of rains. In Central Asia and India are low pressures with high pressures on both sides. This marks a stage of transition. The centres of low pressure still remain, though high pressures advance to expel them. The isobars of July, compared with those of January, (Plates 1 & 2), exhibit in the plainest manner the altered condition of the atmosphere—Asia, the greater part of Europe and North America having, in the former month a low, in the latter a very high barometer. This last explains to us why, in early spring, when a new adjustment of the atmosphere commences, east winds are so prevalent. The accumulation over Siberia, confined by mountains on the south and east, then flows off towards the west.

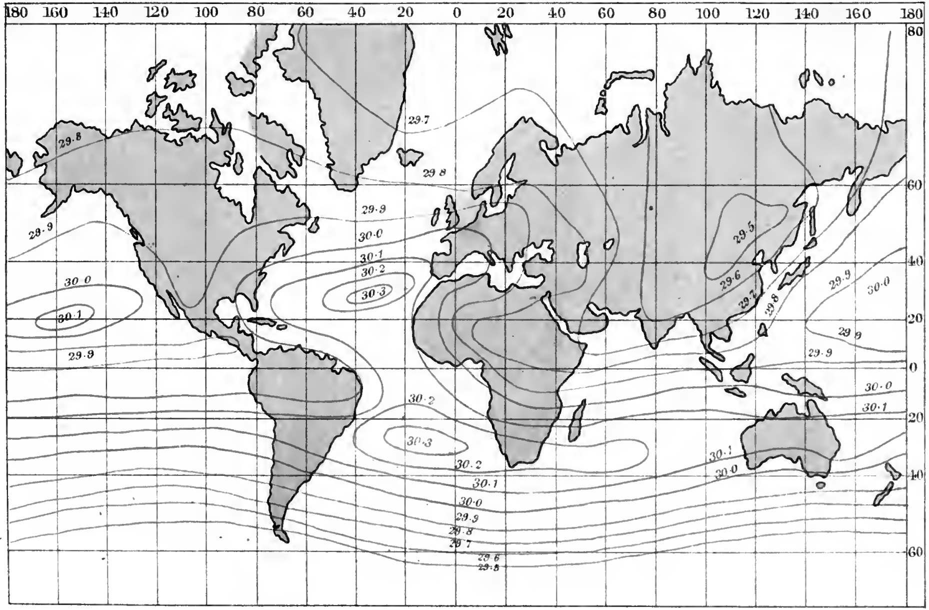
PLATE 3.



ISOBAROMETRIC LINES SHEWING THE MEAN ANNUAL BAROMETRIC PRESSURE.

Mintern Bros. lith.

PLATE 2.



ISOBAROMETRIC LINES FOR JULY.

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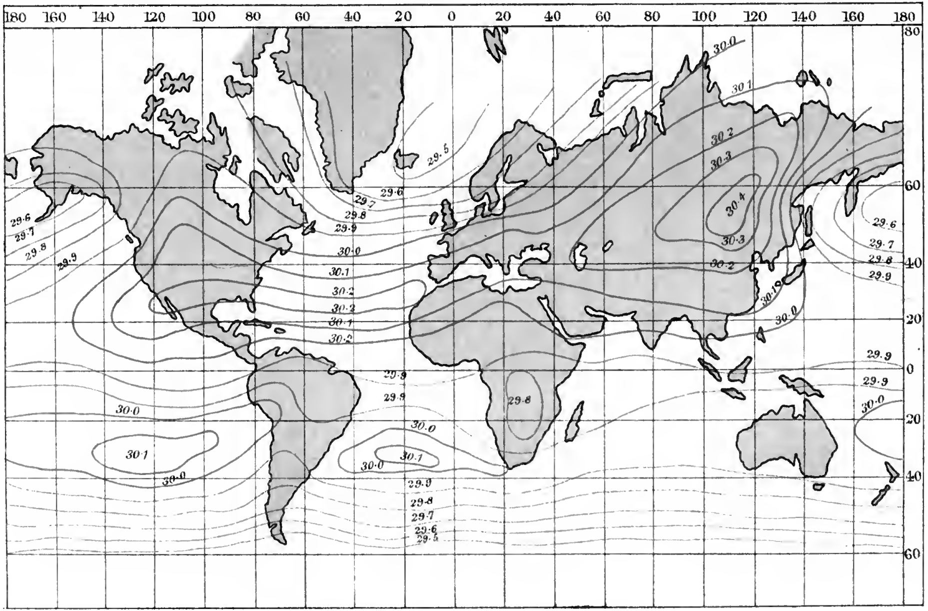
PLATE 1.



ISOBAROMETRIC LINES FOR JANUARY.

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CHAPTER XII.

Winds.—Land- and Sea-breezes—how caused—aspirated or propelled.—The Trade-Winds—their limits in the Atlantic—in the Pacific Ocean.—Deflection of the Winds.—Effects of the Earth's rotation.—Revolution of the Plane of Oscillation.—Belt of Calms.—The returning Winds or Up Trades—winds neither polar nor equatorial.—Zone of Tropical Calms.—Maury's Theories.

WIND is a plainly perceptible current of air in the atmosphere, ordinarily caused by inequality in the temperatures of adjoining regions. If a column of air anywhere receives an accession of heat, it dilates, and, confined on all sides by the surrounding air, it rises above the general level and flows over. Thus losing some of its mass, it becomes lighter than the adjacent cooler air, which restores equilibrium by flowing into it below—the warmer air running in a current to the cooler air above, while the latter hastens in a current to the former near the ground. The flow of air caused by heat is a familiar phenomenon. The fire lighted in a room creates a strong current or wind, which ascends the chimney. The draught of air from a cold to a warm room is felt at once; and the flame of a taper will show that the cool air enters the warm room at the bottom of the door, while the heated air makes its way out at the top. Thus every disturbance of temperature in the atmosphere is followed by a circulation of air, which on attaining a certain magnitude is called wind.

The connexion of wind with the temperature of the air is exemplified in the plainest manner by the sea- and land-breezes so regularly occurring on coasts, and especially on the coasts of islands in low latitudes. As the sun rises the land absorbs heat, and the air above it growing warmer than that over the sea, ascends and gives way to an inflowing cooler current, drawn perpendicularly on the shore. This is the sea-breeze. Towards evening, as the heat declines, the sea-breeze dies away; the land rapidly cools, and at sunset the aerial current changes, and begins to flow from the land to the now warmer sea, this land-breeze growing stronger till the time of the maximum cold or a little before sunrise. It then suddenly ceases and is succeeded by the sea-breeze.

These alternating daily winds are well described by Dampier in the following words :—" The sea-breezes commonly rise in the morning about 9 o'clock, sometimes sooner, sometimes later. They first approach the shore as gently as if they were afraid to come near it ; and oftentimes they make some faint breathings, and as if not willing to offend, they make a halt and seem willing to retire. I have waited many a time both ashore to receive the pleasure, and at sea to take the benefit of it."

" It comes in a fair small black curl upon the water, while the sea between it and the shore is as smooth and even as glass. In half an hour's time after it has reached the shore it fans pretty briskly, and so increases gradually till 12 o'clock, when it is commonly strongest, and lasts so till 2 or 3 a very brisk gale ; at the same time it veers off to sea two or three points or more in very fair weather. After 3 o'clock it begins to die away again, and gradually withdraws its force, till all is spent ; and about 5 o'clock, sooner or later, according to the weather, it is lulled asleep and comes no more till the next morning."

" Land-breezes are as remarkable and quite contrary to the sea-breezes ; for when the latter have performed their offices of the day, by breathing on their respective coasts, they retire in the evening or lie down to rest ; when the land-winds, whose office is to breathe in the night, moved by the same order of divine impulse, do rouse out of their private recesses, and gently fan the air till the next morning ; and then their task ends, and they leave the stage."

He goes on to say that " these alternating breezes are as regular as day and night," which may be true at any one place ; but in different places they exhibit much variety. On the eastern sides of islands within the tropics, the sea-breezes are much stronger, and the land-winds much weaker than on the western, because the former are reinforced, the latter opposed, by the prevailing wind of low latitudes. The same breezes are particularly strong on promontories, on which many currents may converge, while they are feeble or disappear altogether in deep bays. They have little height, and, however freshly they may blow, never affect the clouds. It is related by M. von Buch, that at Laguna in Teneriffe he saw two windmills a little distance asunder, one of which, on the summit of the hill, was always turned to face the constant north-west wind, while the other, halfway down, about 900 feet above the sea, as constantly faced the sea-breeze from the south.

These alternating winds, arising from the daily variation in the relative temperatures of land and sea, are not strictly confined to tropical regions, but may be found on any coast under a hot sun and clear sky. They are observable in many parts of the Mediterranean Sea. The movements of the Corsican fishermen in the Bay of Ajaccio are regulated wholly by them. It has been remarked on the coast of Holland that during the day the wind inclines to the land more than at night; and traces of a similar variation were found by Scoresby even on the eastern coast of Greenland. Sea- and land-breezes blow at times on the Swiss and North-American lakes. On the southern shore of Lake Erie a sea-breeze is felt at a distance of 25 miles. But it is not between sea and land alone that vicissitudes of temperature take place, which manifest themselves by the winds they give birth to. In a mountainous district, the exposed summits and the sheltered valleys, bare rocks and dense forests, the slopes facing the sun and those turned from it all differ in the course of their varying temperatures; and consequently in every alpine country each valley has its peculiar periodical breeze, all conforming to the general rule that the warm air flows to the cool air above, while the cold current in the opposite course runs below. Thus the circulation of air caused by differences of temperature is fully proved by experience.

Winds considered as to the manner of their origin, may be described as aspirated or propelled. We may conceive of a current of air drawn to a point or forcibly driven to it. These two cases are not always easily distinguishable, as attraction and impulse intimately correspond and often coexist. But it is evident that aspirated winds drawn by increase of temperature are propagated backwards. If a warm south wind suddenly appears in England, it will probably be found that it was first felt in the north, perhaps first at Aberdeen, then a day later at Edinburgh, then at York, and finally in London. But in judging of the source of the wind, its deflection must not be overlooked. A south wind must come more or less from the east of south, a west wind from the south of west, the curvature of its course being inversely as the strength of the wind. As aspiration generally proceeds from land, or in low latitudes from the surface of the sea, winds produced by it belong to the lower regions of the atmosphere. The down trades and all monsoon winds may be regarded as low winds, and are always moderate till interfered with by currents from above.

The hottest part of the earth is that whereon the sun's rays fall vertically, or where the luminary at noon is in or very near the zenith. That is evidently the equatorial zone, lying between the tropics, and having always some line directly beneath the sun's path. On the earth's surface, indeed, the maximum heat at the tropics exceeds that ever experienced at the equator, where dense clouds evermore intercept the solar rays. But the depression of temperature due to clouds and evaporation is confined to the surface of the ground. We may be assured that above the clouds solar heat attains its maximum at the equator, and that it there operates effectually, the evaporation below corresponding to the heat and absorptive power of the atmosphere above, while at the same time currents of air or winds rush from both hemispheres to make good what has been carried off by the ascending vapour.

These regular winds, blowing towards the equator from both hemispheres with a steadiness favourable to navigation, have been on that account named the trade-winds, or simply the Trades. Discovered by the Portuguese in the 15th century, they were still so little known in the 16th, that the companions of Columbus were alarmed by their constancy, so strange and unaccountable did it appear, and so likely to baffle their endeavours to return homewards. The region in which these winds prevail has a mean breadth of about 45 degrees, changing its position to the north or south according to the season, and thus embracing within its extreme limits at least 60 degrees. The lines that mark its bounds do not coincide with parallels of latitude, but rather with isotherms or lines marking equal temperatures (from 72° to 77° Fahr.). They extend further from the equator in the northern than in the southern hemisphere, and in the Atlantic than in the Pacific Ocean. The mean northern limit of the trade-winds in the Atlantic lies in summer (September) in lat. 32° N., in winter (December) in lat. 22°. On the eastern side, however, of the same ocean, the trade-wind in summer reaches the shores of Spain and Portugal (lat. 36° N.), or even to the Azores (lat. 39° N.). Ships from Europe bound to America, expect at that season to fall in with the trades somewhere between the Azores and Madeira. They take care to keep at a distance from the coast of Africa, where the wind is not only weaker, but frequently veers round to the north or north-west; that is to say, it tends to become a sea-breeze on the African shore. In winter, when the sun going southwards is followed by the whole system of regular winds, the trade-wind in the northern hemisphere retires within its lowest limits. (See Plate 7.)

In the southern hemisphere, on the other hand, the outer summer limit of the trade-winds in the Atlantic Ocean is found on the eastern side near Africa, in lat. 28° or 30°, on the western side in lat. 32° S. Its limits in winter (the summer of the northern hemisphere) lie somewhere about the 18th parallel S. The belt of calms which separates the trade-winds of the two hemispheres being always north of the equator, the southern trades occupy a broader tract; they also blow with more strength, and make consequently a greater angle with the equator, or have less of east in them than the corresponding winds of the northern hemisphere.

In the Pacific Ocean the zone of trade-winds is somewhat narrower than in the Atlantic, and lies further to the south. The belt of calms, with a breadth of about five degrees, oscillates annually between lat. 2° S. and 8° N.; while the mean limits of the trades on both sides are in lat. 26°—the north-east wind fluctuating between 21° and 31° N. lat., the south-east between 23° and 33° S. lat. But the latter is much interfered with by the numerous groups of islands scattered over the Great Ocean south of the equator; so that it blows with regularity only over a distance of about 50 degrees from the Galápagos to the Marquesas Islands, while the dominion of the north-east wind at the other side of the equator extends 75 degrees further west. It was owing to the constancy and moderation of the winds between Acapulco on the American continent, and Manilla in the Indian archipelago, that the Spaniards who first navigated the Great Ocean entitled it "The Pacific." In the Indian seas, south of Asia, the system of the trade-winds is thrown into disorder, the south-east wind alone maintaining its position between Australia and Africa. The trade-winds never reach within 150 miles of the western shores of America.

The trade-wind or current of air which flows to supply the ascending current at the equator, may be supposed to move in the first instance along the meridian; but it cannot long persist in that course. All movements about the earth, made by bodies not strictly attached to it, are more or less deflected from their original direction, with respect to the earth's surface, by the rotation of the globe. The effects of rotation are threefold:—First, since the circles of latitude between the equator and the poles revolve with velocities differing as the cosines of latitude, the direction of motion from one latitude to another is affected by this discordance. Secondly, rotation gives birth, as has been already explained, to centrifugal force, whence arises an impulse towards the equator, attaining its maximum in lat. 45°. Thirdly, rotation creates a constant tendency to change of direction in rectilinear motions at any fixed point.

Since the earth rotates on its axis from west to east in 24 hours, every point on its surface has a velocity in that direction proportional to its distance from the axis, or to its cosine of latitude. Consequently, if a man could soar in the air at absolute rest, wholly unaffected by the rotation of the globe, he would see the earth's surface fly by him with the velocity, at the equator, of 17 miles in a minute; in lat. 60°, with half of that speed; while at the pole it would wheel round with only half the speed of the hour hand of an ordinary clock. The supposed spectator would see the earth turning towards the east, while he himself, seen from its surface, would appear to go westwards, and with greater velocity the nearer the equator.

But suppose him to start from a point on the earth at the equator (A, fig. 69), and to fly northwards in the direction of the meridian with a speed of 15 degrees, or about 900 geographical miles in an hour. Now his starting-point goes eastwards at the same rate. In an hour he has advanced on his northerly course 15 degrees, and retaining the velocity also of his starting-point, he will have gone in four hours 60° to the north and 60° to the east. But the degree in lat. 60° being only half of the equatorial degree, he will alight in that latitude on the 120th meridian, or 60° east of the meridian which might have been reached on the equator. With equal velocity to the N. and the E., his course will be the diagonal of the parallelogram A B C D. In short, a body sharing the earth's rotation, must, in going from greater to less circles (that is to say, from lower to higher latitudes), carry with it an excess of rotatory velocity which will set it to the east of the meridian from which it started; or to the west if it goes from less to greater circles, or from the pole to the equator. This deflection is always to the right hand in the northern, to the left in the southern hemisphere. (See fig. 70.) The trade-winds, therefore, blowing from lat. 30° towards the equator, bend westwards, and become, in general terms, N.E. winds in the northern, S.E. winds in the southern hemisphere.

Fig. 69.

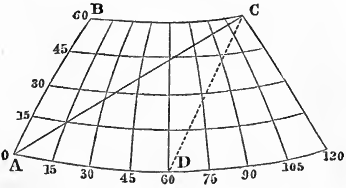
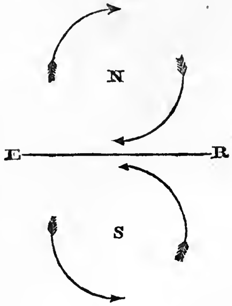


Fig. 70.



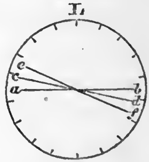
The deflection in question is obviously dependent on two forces, viz. the primary impulse along the meridian, which may vary, and that due to rotation, invariable for each latitude. Hence the degree of inflection varies inversely as the meridional impulse, increasing as that decreases, and *vice versâ*. The stronger wind has the straighter course.

The S.E. trade-wind, being a stronger wind, has consequently a straighter course than the north-east, and meets the equator at a greater angle. The independent movement of the atmosphere being restrained by friction with the earth, the deflection of its currents is not always what the rotation of the earth could account for. The rate of deflection, being dependent on the differences of the successive degrees of latitude, is greatest near the pole, and diminishes towards the equator, but up to this line it never wholly ceases. The deflection once acquired remains though not increasing. Thus the trade-wind north of the equator blows persistently from some point between the north and east. In fact, in the Atlantic it varies from N.N.E. on the eastern side near Africa, to due east at its western limits.

The centrifugal force generated by the rotation of the globe has been already described (p. 121), with its laws and mode of operation. Being weak in comparison with gravity, to which it is always opposed, its effects are much less obvious.

The third effect of rotation has hitherto attracted little notice. It seems impossible to devise any mode of suspending a pendulum which shall leave it completely at liberty and exercise no control over its motion. Yet, if the cord that holds it be long and flexible, a pendulum may vibrate for a considerable time before its tendency is materially interfered with by the fixedness of its suspension. Now, were a pendulum to vibrate, suspended exactly over the pole of the earth, and not in the least restrained at the point of suspension, its plane of oscillation would be seen to revolve completely in 24 hours.

Fig. 71.



It would move round in the same direction as the hands of a watch. If the pendulum be hung over the centre of the divided circle (L N, fig. 71), and swung in the direction *a b*, it will be seen to move with every oscillation from *a b* to the position of *c d*, and thence again to *e f*. At the pole the plane of oscillation will thus revolve completely in 24 hours. In reality, supposing it to be in no degree affected by its connexion with the earth, its plane of oscillation remains absolutely unchanged in general space, while the earth beneath it turns round from west to east; but to an observer on the earth, the ground he stands on seems to be perfectly fixed, while the plane of oscillation moves in the opposite direction. Such is the phenomenon which might be seen at the pole. But south of that point the revolution of the oscillatory movement grows slower continually, till at the equator it ceases altogether. The revolution in question being in reality that of the earth, is uniform on any parallel of latitude or circle perpendicular to the earth's axis; and the horizon at the pole is in that category. There the plane of oscillation revolves with the earth at the rate of about 15 degrees in an hour. But if from the pole we go southwards to any point, Z (fig. 72), the pendulum will now hang perpendicular to Zp, the tangent of latitude or horizon. But Zp (the tangent continued till it meets the earth's axis Po) being the hypothenuse of the right-angled triangle of which Zr (the cosine of latitude) is a side, must be greater than the latter; yet the circles of which Zp and Zr respectively are radii, both revolving on the earth's axis, move together at their circumferences. If we place these in contact (fig. 73), it will be manifest that 15° of the smaller circle of which Zr is the radius, will be less than 15° measured on the circumference of the circle described with the radius Zp. The rate of revolution of Zr, when measured on or transferred to the scale of Zp the tangent, will be diminished in the ratio of Zp to Zr. But Zp is to Zr as Zo, the radius (fig. 72), to $ro = Zs$ (the sine of latitude). Thus it appears that the rate of change of the plane of oscillation varies as the sine of latitude; and consequently its rate at any place may be found by multiplying 15°·0411, the mean hourly rate of the diurnal revolution, by that sine. For experimental proofs of this theory, the following examples will suffice:—

Fig. 72.

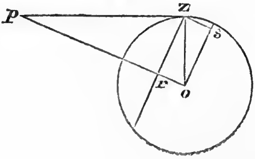
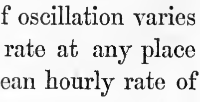


Fig. 73.



	Lat.	Sine.	Revolution.
Ceylon.........	6° 56′	0·1207144	1°·870 per hour.
New York ...	40 44	·6523189	9·733 ,,
Geneva.........	46 12	·7217602	10·522 ,,
Paris...........	48 5	·7527980	11·500 ,,
Bristol.........	51 47	·7856770	11·788 ,,
Dublin.........	53 20	·8021230	11·915 ,,
Aberdeen......	57 9	·8400936	12·700 ,,

It has been erroneously stated, in reference to the effects of the earth's rotation, that the tendency to deviate from rectilinear motion is alike in all directions. But that is manifestly incorrect. The three modes of deflection pointed out in the preceding pages differ much in energy; and the most energetic (deflection by change of latitude) is alone evident to common experience. The winds wherever they are traced, change direction as they change latitude. They are commonly distinguished as equatorial and polar winds; but as north and south winds they cannot long continue. Everywhere the prevailing winds have originated from one or the other of these, and have been deflected by change of latitude. There is no direct correspondence between the pole and equator; indeed it seems naturally impossible for a wind from the pole to arrive at the equator, or one from the equator to reach the pole. The former would become an east wind, the latter a west wind before accomplishing two thirds of the way to the proposed goal.

The trade-winds increase in force towards the belt of calms, or, considering that they are called into existence by aspiration, it would perhaps be more correct to say that they are strongest where first called for, and grow weaker as their distance from that line increases. Brisk breezes when first fallen in with at their outer limits, they grow stronger towards the equator, till they almost become gales. This is particularly true of the S.E. trade-wind, which, in the middle and at the western side of the Atlantic, blows over a much longer course, and more steadily, than the corresponding wind in the northern hemisphere. The S.E. wind rushing from the icy seas of the south polar ocean to the heated waters of the equatorial zone, has much more strength than the N.E., the sources of which in the northern Atlantic lie close to the warm Gulf-stream. The latter wind, most developed near the coast of Portugal in lat. 36°, retires southwards, grows feebler, and veers more to the east whenever approached on the west by that warm current.

The south-eastern trade-wind beginning where the cold current from the south pole shows itself near the Cape of Good Hope, and crossing the equator to nearly 10° N. lat. when the sun is in northern declination, sweeps nearly 40° of latitude with little change of direction ; and though at another season it retires southwards, it never ceases to be a strong wind. On the eastern side of the Atlantic land-breezes (westerly winds) prevail to a distance of 100 or 150 miles from the African coast. On the western side the south-east wind leans to the American continent, and at length the two trade-winds enter the Caribbean Sea, united as an east wind, the belt of calms disappearing altogether.

The zone of vapour-laden and ascending atmosphere, named "the Belt of Calms," or "of the Rains," being created by the excessive heat in the sun's path, necessarily follows the line of maximum insolation. But phenomena of a cumulative kind, or the results of continued action, require time for their manifestation ; and thus the line of ascending atmosphere does not at once follow the sun's change of declination. But set at length in motion as the sun approaches the tropic, it has advanced but a little way when it meets the returning luminary, and therefore its oscillation, instead of extending from tropic to tropic, is confined within comparatively narrow limits. The belt of calms in the Atlantic Ocean lies always on the northern side of the equator, its extreme limits being 1°·45 and 11°·20 N. lat. When reduced to its least breadth (in January) it extends about two degrees northwards from the former of those limits ; when at its greatest (in August) it reaches the latter limit with a breadth of about 8 degrees. In this condition it remains till October, its mean position being about six and a half degrees north of the equator. In winter, or from January to April, it grows narrower, and also goes southward about 4 degrees. But in truth the position of this zone and its limits change with the longitude, so that the accounts given of them by navigators vary not a little. In the Pacific Ocean the belt of calms annually touches, or perhaps even goes south of the equator, its mean position, however, being 3 degrees north of that line. In the Indian Ocean it disappears during the S.W. monsoon, when the sun is in northern declination, and for the remainder of the year lies 10 or 12 degrees south of the equator.

The fact that the mean position of the belt of calms and rains including the line of most active evaporation, by many called the Thermal Equator, is in the Atlantic Ocean not at the equinoctial line, but in all seasons to the north of it, is too remarkable to be allowed to pass without comment. Some would account for it by arguing that the northern hemisphere having most land, must also have the highest temperature, and therefore that the line marking the highest temperature must lie wholly within that hemisphere. But there is no ground for attributing a higher mean annual temperature to land than to sea. Land is indeed more susceptible of extreme temperatures than water; and excesses of heat are everywhere more noted than those, chiefly nocturnal, of cold. Besides, if the northern hemisphere possessed more heat than the southern, might we not expect that its thermal limits would be thereby enlarged rather than contracted? The line of the sun's greatest power being unquestionably at the equator, can it be supposed that the indirect heat of the northern hemisphere, itself derived from the sun, exceeds at any point and overpowers the luminary's direct influence? Others assume that the heat of the African Sahara affects the adjacent ocean. But in the latitude of the great desert of Northern Africa the ocean exhibits no sign of an abnormal increase of temperature. Neither the Atlantic Ocean nor the Mediterranean Sea owe any increase of temperature to the sands of the Sahara. How can the heat of the desert, the mean temperature of which is perhaps not excessive, reach the ocean? Not certainly by conduction through the ground, nor yet through the atmosphere; for by day sea-breezes cool the shores of the desert in which at night the traveller's water-bags are often frozen.

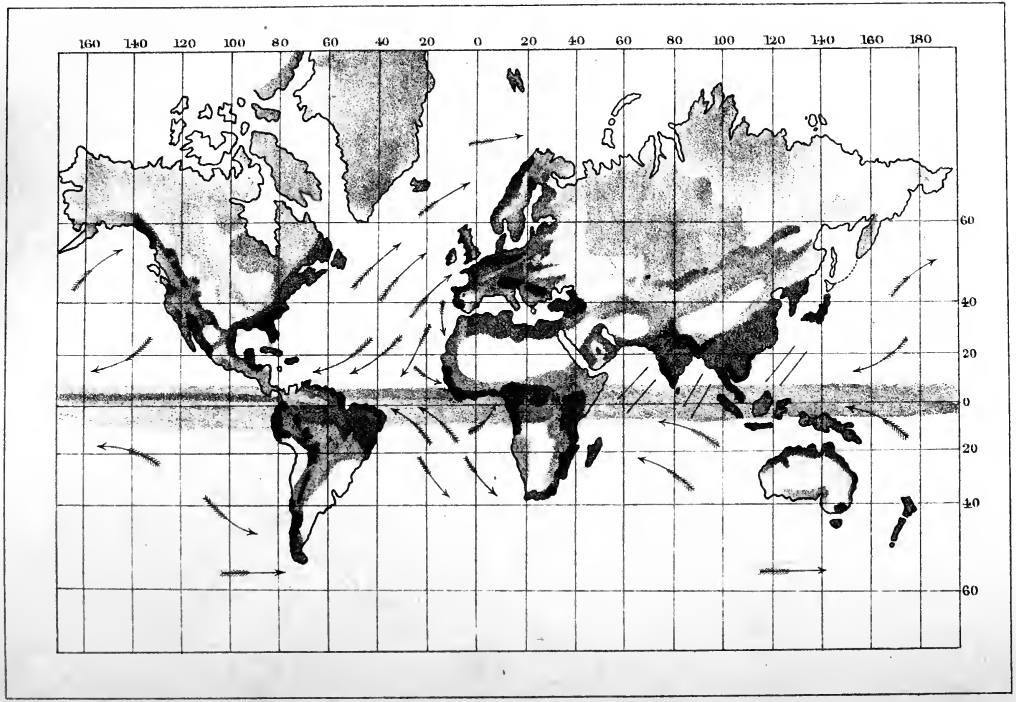
The truth seems to be that the position of the zone of equatorial calms, and of the line of greatest evaporation, north of the central line is due to the preponderant influence of the south polar ocean. It is determined by the concurrent influences of oceanic temperature and of the trade-winds. It will be seen in a chart showing the temperatures of the Atlantic Ocean, that the isotherms bend sharply to the North Polar Sea, marking a warm current which replenishes the northern half of that ocean with waters from the equator. But in the Southern Atlantic the isotherms bend from the pole to the equator, the cold current apparently running N.N.E. to the Gulf of Guinea. Now the trade-winds and the zone that separates them are marked out precisely by isothermal lines. The former start from the isotherm of 72°·5 or 77° Fahr. according to season; the latter lies about that of 81°·5. Owing to the cold current running towards the Gulf of Guinea, the maximum temperature of the ocean and the line of greatest evaporation are driven north of the equator and furthest on the eastern side, where the inequality of temperature is most plainly manifested. The belt of calms is narrower and lies further south on the western side of the ocean; indeed in that quarter it even occasionally comes S. of the equator. Its general obliquity is obviously the result of the oblique isotherms in the Southern Atlantic. When the winds from the two hemispheres are unequal in force, the stronger of course passes the equator; and the vapour driven before them must be accumulated where they meet. In the Atlantic Ocean the south-east trade, being the stronger wind, shows its influence in the position of the northern and more variable limit of the zone of vapour. The southern limit, much less fluctuating, may perhaps be more closely connected with the line of highest temperature and evaporation.

In the Pacific Ocean the opposing trade-winds are less unequal; nor is there so strong a contrast between the temperatures of the oceans to the N. and S., and consequently the belt of calms is less removed from a central position. The Indian Ocean fully shows how little the preponderance of land avails towards placing the belt of calms north of the equator; for during the S.W. monsoon, when the N.E. trade disappears, that belt vanishes also. But during the N.E. monsoon (the regular trade-wind) the belt retires from the northern continent, and is found in lat. 10° or 12° S., the S.E. trade, enfeebled by having the Australian continent at its sources, being there a weak wind.

Navigation in the trades is rendered agreeable by the fresh steady wind and clear sky, varied by a few brilliant clouds at a great height, their shadows flying picturesquely over the waves. This description is most applicable to the outer portion of the zone; for as the calms are approached the clouds thicken, and heavy rain grows frequent. But in general the atmosphere of the trades is as exhilarating and grateful to the seaman as that of the calms is loathsome and depressing. In the latter zone, which sailors, to express the weariness felt in it, call "the Doldrums," the constant gloom, the oppressive sultry heat, the apparent stagnation of the sea (often fetid at the surface), and the heavy languor of all nature, interrupted only by tornadoes or violent thunderstorms with drenching rain, are painfully tedious and more distressing than the roughest weather.

Within this belt of rains all beneath the clouds is dismal and lifeless. But a very different spectacle might doubtless be seen in the upper region of the atmosphere. There, brilliantly illuminated masses of fleecy vapour, like mountains of snow-white foam, incessantly rise to view, we may be assured, and quickened by the sun's rays, flow off to higher latitudes, borne by upper currents returning to replace those that flow in below. The altitude at which this overflow of humid and heated air takes place cannot be learned by observation. But since in temperate latitudes clouds may be occasionally seen at a height of at least 40,000 feet, or 7½ miles, it can hardly be doubted that at the equator, where the cloud-raising agencies put forth all their strength, the vapour-bearing currents probably reach that elevation. Thence the sea of clouds flows off in a direction perpendicular to the line of accumulation, and therefore meridional. The wind that bears it is deflected, however, in its course, as already explained, owing to the rotation of the earth, bending to the right-hand in the northern, to the left-hand in the southern hemisphere—that is to say, towards the east; so that when, descending continually in its course to higher latitudes, it at length reaches the surface of the earth, beyond the outer limit of the trades, or in general about the 40th parallel of latitude, it is a south-west wind in the northern hemisphere, a north-west wind south of the equator.

The aerial current which ascends from the belt of equatorial calms is laden with the collected vapour of the intertropical ocean, and is therefore fully saturated. It may part with some of this vapour on rising to a great altitude; but that effect of reduced temperature is then in some measure counteracted by reduced pressure, and aqueous vapour has the power of retaining the gaseous form at a temperature much below that which is necessary for its formation. On leaving the zone of greatest heat it



REGULAR WINDS & RAINS.

gradually descends, so that on its course from its elevated starting-point till it reaches the surface of the earth it probably undergoes little change of temperature. As it goes northwards, however, some of its humidity must be precipitated. This condensation of vapour sets free latent heat, which gives fresh elasticity to what remains. The zones of the earth also continually grow less, so that with the decrease of the humidity conveyed decreases also the area to be supplied. Thus the south-west wind in the northern hemisphere, wherever it proceeds from the ocean, is a humid and warm wind. These equatorial winds, returning from the belt of calms to temperate latitudes, change position with the season, moving northward or southward in the same manner as the trades, which blow beneath them in the opposite direction. Since they partake of the regularity of the latter, they have also some title to be called trade-winds. By some eminent writers they have indeed been styled Anti-trades, a name implying an opposition which has no existence. It would be well therefore to distinguish these two main branches of the atmospheric circulation, to and from the equator, as the Down and the Up Trades. (See Plate 7.)

The line which marks the descent of the S.W. wind on the Northern Atlantic Ocean and Western Europe is neither distinct nor invariable; and, besides, it is impossible on the coast to distinguish the equatorial wind from sea-breezes. We may, however, assume that the line in question oscillates on the ocean between the 30th & 45th parallels of latitude. The S.W. wind is felt in summer on the summit of Teneriffe (12,182 feet), while the N.E. trade blows about 1500 feet lower down; and when the latter in winter retires southwards (its sources also retreating) the upper wind descends to the sea. But, unlike the down trades, it has not the sole and undisputed possession of the region on which it enters. In the ectropical portions of the globe, and especially between the tropics and polar circles, winds blow from all quarters, and very frequently from the centres of intense cold. The dense cold air of the icy shores of North America flows southwards; but the Rocky Mountains, running from N.W. to S.E., turn this current eastward to mingle with and cool the equatorial current. From the Siberian centre of cold flows another frigid stream;

and this again, being restrained by the Yablonnuy and Altai mountains, is turned to the west, and gathering strength with heat, reaches Europe as a very persistent east or south-east wind extremely cold and dry. On the Atlantic Ocean, and chiefly at its eastern side, the south-west and north-east winds often blow side by side; and when they come into collision the stronger forces back the weaker; so that these currents shift their positions, going further east or west according as the one or the other comes off victorious in the struggle. Hence the zone of the S.W. wind is also that of the changeable winds. To the variable predominance of these winds of opposite characters is due the fickleness of climate that characterizes our portion of the temperate zone. In the annual fluctuations of climate there is often perceived a strong contrast between Western Europe and North America, or Southern Russia. When we have an unusually warm and wet summer, a want of heat and moisture is felt in the United States; when they have both abundantly, we suffer from a dry cold wind. Such are the vicissitudes that attend the movements of the S.W. and N.E. currents of air.

Just views respecting the principal currents of the atmosphere are so important, that it seems expedient here to advert to certain statements as to their mutual relations which have no solid foundation. By some eminent authors the down trades and up trades are respectively entitled Polar and Equatorial currents; and these designations are often intended not merely to indicate the direction of the winds, but to imply an actual interchange between the polar and equatorial regions of the atmosphere. These winds, we are told, are mutually compensating currents. But winds must be regarded rather as consequences of disturbed equilibrium in the atmosphere than as direct agents in its restoration. It is impossible that in an atmosphere several miles in height, a local deficiency anywhere at its base should have to be made good by a narrow horizontal current at a comparatively slow rate. The trade-winds do not come from the pole, and the returning winds or up-trades as certainly never reach the pole. To do so they ought to adhere to the meridian, which is naturally impossible. The impulse that drives winds along the meridian is incidental and irregular, while the force that diverts them from it is constant for every latitude, and increases continually towards the pole. When it is considered that the zone of the trade-winds occupies half of the earth's surface, while the pole is but a point, the absurdity of supposing a perpetual interchange of aerial currents between them will be quite evident. If the currents of air thrown off daily from the equator were to meet at the pole as in a focus, the result would be perpetual storm and atmospheric commotion in a region which actually appears to be particularly exempt from such visitations.

In Lieutenant Maury's volume on the Physical Geography of the Sea, much zealous industry and ingenuity have been thrown away in support of irrational and fantastic theories. We cannot believe with him that the trade-winds (N.E and S.E.) cross each other in the region of calms, the former going off as the N.W. up trade of the southern hemisphere, the S.E. trade as the S.W. of the northern Atlantic, that they hasten each to its pole, there ascend in a certain vortex, then turn again towards the equator by invisible routes beyond the reach of observation till they again descend in the character of down trade-winds. These movements are rendered still more mysterious by being represented as the effects of magnetism. That magnetism should raise streams of air at the poles and the equator, and let them fall in middle latitudes, is not less surprising and incomprehensible than that it should choose to perform those feats between the terrestrial poles or the extremities of the earth's axis, instead of between the magnetic poles. The course of "this particle of air" through the upper regions of the atmosphere, as Lieutenant Maury remarks, "does not appear to have been very satisfactorily explained by philosophers." In truth it does not appear that any one has ever thought of explaining it; and since it can neither be explained as a theory nor proved as a fact, it ought to be dismissed as a groundless assumption.

CHAPTER XIII.

The Monsoons—their Limits—regular and alternating.—Winds of the Polar Circle.—The East Winds the prime movers.—Table of Comparative Frequency.—Effects of Heat and Deflection controverted—Table of the Strength of Winds.—West Winds subordinate—East Winds the prime movers in Aerial Circulation.—Objections.—The Barometer, what it Measures.

The trade-winds, it has been seen, are completely developed only over the ocean and at some distance from land. Under such circumstances the periodical change in the winds occasioned by the sun's passage across the equator on his way from tropic to tropic, is confined to a general movement of the whole wind-system to the north or south according to the course of the luminary. Otherwise, or where land interferes, the north-east and south-east winds prevail alternately, the one being suppressed while the other holds sway, though often changed from its original course by the aspiration of land. Where this occurs, as on the coasts of India and generally throughout the Indian Ocean, the alternating winds are called Monsoons—that is, season winds, from the Malay corruption of *Mausim*, an Arabic word signifying recurring periods or seasons.

The trade-winds blow constantly and contemporaneously, only shifting position a little with the sun's declination. The monsoons blow alternately, and in truth may be described as sea-breezes exempt from nocturnal interruption, as they all, with little exception, blow from the sea to the land in summer, and from some continent to sea in winter. They are found on the grandest scale and in the greatest variety in all the seas south of and adjacent to the Old World, from the eastern coast of Africa eastward through the Indian Archipelago to the coral islands of the Pacific (Pl. 7). Eastern Asia presents the most extensive and compact surface of land on the face of the earth, lying far to leeward of any currents of air from the warm ocean. Hence it is in winter a vast region of the most intense cold. Under its condensed air the barometer rises to a great height. But the cold air sinks to the ground and is confined, on the south by ranges of the highest mountains on the globe, on the east by a range (the Yablonnuy) rarely less than 3000 ft. in height. Through these, however, some of it escapes, and flowing as a N.E. wind over Corea and China, carries intense cold occasionally even to the southern shores of the latter country. A north-east wind reaches the Indian peninsula also, not from Siberia, however, but from a nearer source and much less cold. Again, a N.E. wind collects the vapours of the Red Sea and sheds them as the scanty winter rains on the eastern highlands of Abessinia to a height rarely exceeding 5000 feet.

But when the sun advancing northward crosses the equator, these N.E. winds do not retire northwards like the trades, but cease altogether. Retire northwards they cannot, because in that direction, at no great distance from India, the Asiatic continent is crossed by ranges of the highest mountains with the most elevated and extensive tablelands on the earth. These completely bar communication in the lower strata of the atmosphere, on which the meteorology of every country, so far as climate is concerned, almost wholly depends. Besides, as the sun approaches, the condensed air of Eastern Asia, relieved from the fetters of frost, rises up and disappears, and an extremely light atmosphere succeeds to a very heavy one—this change extending also over China and India, and even reaching North-eastern Africa. Nowhere on the earth, except perhaps at the poles, does the barometer fall so low in summer as in the heart of Siberia, about Irkutsk; and the depression, which there has its maximum, extends widely over the south-eastern part of the Old World.

To supply this atmospheric deficiency, the south-east trade crosses the equator. There, as it encounters no north-east wind, it is not stayed by a zone of calms and rains, but, guided by the aspiration of the land, it shapes its course accordingly, and falls on the coast of Malabar as a south-west wind. This great change of direction in winds so near the equator cannot be ascribed to the deflection caused by the earth's rotation, but is evidently due to the strong aspiration of the land to the north-east, which alone can account for a south-west wind blowing in summer from Eastern Africa to India. The season of the south-west winds on the coasts of Zanzibar is the season when they occur, though they cannot be said to prevail over the south-east winds; and the occurrence of both at the same season proves that the former do not owe their deflection to a perfectly constant cause (Pl. 7).

When the sun passes from northern to southern declination, the N.E. wind resumes its sway over the Indian Ocean and crosses the equator southwards. Then, being deflected to the left in the southern hemisphere, it penetrates as a north or north-west wind to the centre of Australia, which in the heat of summer strongly attracts it. To the warmth of this continent is doubtless due the weakness of the south-east trade in the Indian Ocean.

The monsoons of the Indian seas from the Philippine Islands to the coast of Africa exhibit so many local modifications and such complicated diversity, that no exact account can be given of them within narrow limits. The periodical winds called monsoons, met with in the Gulf of Mexico, on the coast of Guinea, in the Black Sea, the Caspian Sea, &c., are in truth winds due to the aspiration of the land, like sea-breezes. They blow from sea to land in the hot season, and exemplify in the plainest manner the generation of wind by excess of heat. It is obvious that this aspiration or attraction of wind by land can operate only on the lower strata of the atmosphere; and therefore all winds due to that cause, and in derogation of the general wind-system, must be comparatively low. Thus the N.E. monsoon in the Red Sea rises to only half the height (about 4000 feet) of the frontier mountains of Abessinia; and while the south-west monsoon blows from Zanzibar to the coast of Malabar, the south-east trade-wind high above it carries to the same country the copious rains that flood the Nile.

There is one wind, not a trade-wind nor a steady monsoon, though in some respects resembling both, and yet important enough to stand alone, unclassed. The south-west wind which from the Gulf of Mexico blows over the valley of the Mississippi and carries warm rain to the United States, performs for that country the office which the up trade of the Atlantic Ocean discharges for Western Europe. It springs from a very warm sea.

Doubtless the land to the north of it is often warmer, and so attracts the vapour-laden air. But probably it often happens that the atmosphere over the land, condensed with cold, leaves a vacuum above which attracts the warmer and lighter air. On the North-American continent there is no chain of mountains running from W. to E. to bar the communication between the atmosphere of the frozen polar sea and that of the torrid zone. Consequently intensely cold winds often descend in the valley of the Mississippi much below the tropic. In New Mexico and Texas, sudden changes of temperature to the extent of 60° often take place in a few hours. The prevalence of the warm S.W. wind rarefies the air and lowers the barometer; then the north wind (las Nortes) rushes in and all is frozen. To the collision of opposite currents of air, of widely different temperatures and therefore causing very violent movements in the atmosphere, is to be ascribed the frequency of destructive tornadoes in the interior of the United States, chiefly in the valley of the Mississippi.

The ocean presents a uniform surface, everywhere alike favourable to the reception of the sun's rays. Slight, therefore, as are the differences of temperature between its neighbouring zones, the least preponderance is instantly discernible in a balance so nicely adjusted. But on land the gradation of heat is not so uniform and continuous. Bare rocks and naked plains at some distance from the sun's path may experience a much higher temperature than a region of woods and forests immediately beneath it. It is probable, therefore, that the distribution of heat on the land between the tropics is irregular, and that the hottest points in that zone do not all lie in the same parallel of latitude. Hence too it may be doubted whether the trade-winds be developed on land as over the sea. And since on land the ascending current of air between the trades must want the strength derivable from the copious vapour of the ocean, those returning upper winds from the S.W. and N.W., which have their courses on land, are probably weak and dry winds. Certainly the S.W. and W. equatorial winds of the northern hemisphere are entirely oceanic; and hence in the Old World dryness of climate is the necessary consequence of being far to leeward of the ocean. The W. (more frequently N.W.) wind of the United States, cold and dry, issues from the pole. The S.W. wind which reaches the Caspian Sea from Africa is also a dry wind.

The polar circle belongs to the region of changeable winds; but which of these predominates is still undecided. Some say that in the north polar seas the west wind is most frequent; others report that the N.E. wind prevails. But the probability is that no one rule holds good for the whole polar region, and that every quarter round the pole has a different wind-system. It is, however, certain that there is much more calm in those icy climes than elsewhere. The air seems, like the sea, to be bound by frost. It is during the calms that the temperature falls lowest. When the wind begins to blow or snow to fall, from whatever quarter, temperature rises; but the cold reduced in this way is much less endurable than the more intense cold of a perfect calm.

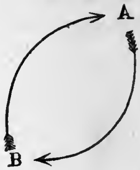
It is obvious that the down trade-winds, which ultimately become east winds, are the prime movers in the system of regular winds. They are not derived from any other wind, but are called into existence by equatorial heat. As offspring of the sun, they follow the sun in its movements between the tropics. The central zone of the earth, lying between the parallels of 30° north and south, contains exactly half of the earth's surface, the area of 30 degrees next the equator, being equal to that of the remaining 60 towards the pole. That equatorial zone may be said to be occupied exclusively by the trade-winds, which are also constant. If with these we compare the returning winds or up trades, we perceive that the latter manifestly spring from the former, and cannot exceed, though they may possibly fall far short of them in volume. The upper current at a great height must be much less dense than that at the surface of the ground; and when at length it descends as a south-west wind, it has to fight its way through contending currents to obtain a footing on an area which, the polar regions being deducted, is probably less than three eighths of the earth's surface. The following Table shows the comparative frequency of winds from east and west quarters at different places within what is deemed the domain of the west wind; the numbers represent frequency and strength combined.

Moscow	N.W. 238	S.E. 165
St. Petersburg	W. 180	E. 130
Upsala	S.W. 261	N.E. 113
Copenhagen	W. 186	E. 118
Brussels	S.W. 271	E. 133
London	S.W. 254	N.E. 147
Paris	W. 190	E. 127
Berlin	W. 214	E. 128
St. Gothard	N.W. 519	S.E. 239
New York	N.W. 199	S.W. 180
Trenton (New Jersey)	S.W. 229	N.E. 144
Nashville (Tennessee)	S.W. 391	N.E. 145
Fort King (Florida)	S.W. 222	N.E. 140
Woolnorth (Van Diemen's Land)	W. 332	E. 174

From this it is evident that although west winds certainly predominate in high latitudes nearly as 2 to 1, yet they are far from having the exclusive mastery of any zone. In truth the zone of westerly winds may also with much reason be described as that of variable winds. On the other hand, the trade-winds, inclining from the east, constant on half of the earth in the central zone and set in motion by the sun, must be regarded as the primary winds, constituting the mainspring of the atmospheric circulation over the globe.

Irregular winds are so frequent, so diverse, and comparatively unimportant, that the study of them would be unproductive labour. Every change of temperature, every fall of rain causes some movement in the atmosphere; and movements of this sort interfering with each other may bring about serious disturbance. Among the most ordinary phenomena of the atmosphere are oscillating currents of air; that is to say, if a current flows to day from north to south, it will probably tomorrow return from south to north. But in these movements it veers or is deflected (in the northern hemisphere) to the right hand. Hence in seaman's phrase it goes round with the sun—that is, from east by south to west, or to the right hand of one looking southward. In going

Fig. 74.



from north to south, A (fig. 74), bending to the right, performs the semicircle A B; and returning from B to A with like deflection, it completes the circle, as pointed out by Professor Dove, and goes round in the same direction as the sun. The wind, it is true, does not always veer in this way, but sometimes takes a retrograde course. In this case it rarely completes its circuit; and the winds that "go round with the sun" are found to be in our latitude more numerous than those that veer in the contrary direction, in the proportion of nearly 3 to 1.

Where disturbance is frequent, violence is not unlikely to occur. The wind exhibits at times a force hardly credible. Its commotions are due perhaps to the descent of elevated currents, which at a distance from the friction of the earth's surface have acquired a great velocity; and in that lies its strength. Storms of wind ordinarily occur about the equinoxes, when, as the sun crosses the equator, the monsoons change and a general movement takes place in the whole wind-system. Currents of very different temperature then come into collision; and their rapid change of place, the cold stream descending and the warm rising above it, disorders the whole atmosphere. The connexion between strength of wind and its velocity may be learned from the following Table, used by seamen :—

The Beaufort Scale of Winds.

	Velocity.
1. Light air, sufficient to give steerage-way	2 miles per hour.
2. Light breeze, sufficient to give 1 to 2 knots	4 ”
3. Gentle breeze, sufficient to give 3 to 4 knots	8 ”
4. Moderate breeze, sufficient to give 5 to 6 knots	16 ”
5. Fresh breeze, royals	24 ”
6. Strong breeze, single reefs and top gallants	32 ”
7. Moderate gale, double reefs	40 ”
8. Fresh gale, triple reefs and courses	50 ”

	Velocity.
9. Strong gale, close reefs	62 miles per hour.
10. Whole gale, close-reefed maintop ..	78 ,,
11. Storm, storm stay-sails...............	96 ,,
12. Hurricane, bare poles	120 ,,

To this may be added the American Table, which affects greater accuracy.

Velocity.		Pressure on the square foot in lbs. avoirdupois.	
Miles in 1 hour.	Feet in a second.		
1	1·47	0·005	Hardly perceptible.
2	2·93	0·020	Plainly perceptible.
3	4·40	0·044	
4	5·87	0·079	Gentle breeze.
5	7·33	0·123	
10	14·67	0·492	Lively breeze.
15	22	1·107	
20	29·34	1·968	Brisk gale.
25	36·67	3·075	
30	44·01	44·29	Strong gale.
35	51·34	6·027	
40	58·68	7·873	Very strong.
45	66·01	9·963	
50	73·35	12·300	Storm.
60	88·02	17·715	Great storm.
80	117·36	31·490	Hurricane.
100	146·70	47·200	Destructive hurricane.

From what precedes, it will have been seen that the regular winds all arise from the circulation established between the torrid and the temperate zones. The currents of air flowing towards the equator from the N. and S. become respectively N.E. and S.E. winds. Those returning from the equator above the latter reach the earth's surface as S.W. and N.W. winds. Between the trade-winds (N.E. and S.E.) is the zone of calms, so called because dead calms frequently occur in it. Although exempt from the regular winds, it is frequently visited by tornadoes or sudden thunder-storms accompanied by violent gusts of wind and heavy rain. Between the outer limits of the trade-winds and the inner limits of the returning or upper currents, are also zones of calms, differing from the equatorial zone by their dryness much more than by their temperature.

The generally accepted views respecting the origin of the regular winds, explained in the preceding pages, have been recently controverted by a Professor of physical science*, who assures us that the winds, no less than the fortunes of men, are ruled by the stars. The doctrines thus assailed are in themselves so interesting and important, and their subversion threatens with confusion so wide and well cultivated a field of inquiry, that they ought not to be surrendered at once to merely specious subtlety. The author in question denies the agency of heat in the creation of wind. "The heat of the African Sahara," he says, "or of Arabia, far exceeds that of the equatorial ocean; yet air flows from lat. 40° over the Atlantic Ocean to the equator and not to the great desert." He thence concludes that as "the trade-winds do not blow to the hottest parts of the globe," they are not due to heat; for "if a difference of 40° of heat be insufficient, how can 15° or 20° move the atmosphere?"

Now, to the statement that the mean temperature of the great desert exceeds that of the equatorial ocean (81°·5 Fahr.) by 20° or 25° we must at once demur. We are aware that a temperature of 152° has been observed in the desert; but it was in the sun and near the ground, and showed the power of reverberated heat; it did not give the mean temperature of the air even for the hours of daylight. We know also that at Morzuk (lat. 19°) the thermometer at night ordinarily falls below 60°, and in winter below the freezing-point. In speaking of the heat of the Sahra, mean and extreme temperatures are too often confounded. It may well be doubted if the mean temperature of the column of air above the Sahra, taken in its whole height, ever exceeds or even equals that of the equatorial ocean. Neither is there any reason to believe that the atmosphere over Northern Africa or Arabia ever exhibits the deficiency continually experienced at the equator and periodically in Asia, and which occasions an influx of air, by the trade-winds in the one

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* Physical Geography in its relation to the prevailing Winds and Currents, by John Knox Laughton, M.A., F.R.A.S., F.R.G.S.

case, by the S.W. monsoon in the other. It has been already remarked that though the current of air sets from coolness to warmth, it does not necessarily flow to the hottest parts. Differences of atmospheric temperature are greatest near the ground, where communication is most impeded. Heat gives the impulse; but the guidance is due to circumstances. Between the sources of the trade-winds in lat. 40° (or rather 36°) and the great desert, the mountain-chain of Atlas extends through a length of nine hundred miles. South of lat. 30° this obstacle disappears; and there the higher temperature of the land produces a sea-breeze. But towards the north the continuous decrease of temperature has more effect, and the Libyan deserts are refreshed by N. and N.E. winds. That which necessitates an influx of air is an ascending current with low barometric pressure. This condition exists over the equatorial ocean, and not on the Sahra.

Again, Mr. Laughton denies that any deflection of the wind can be caused by the earth's rotation; and thus he argues:—"The difference between the hourly speed of a point on the parallel of 30° and on the equator is 120 miles. If, then, a quantity of air were to be suddenly transposed or were to move without friction, from the parallel of 30° to the equator, it would manifest itself there in a storm of unheard-of severity, wind in the most violent hurricanes seldom attaining a velocity of more than 100 miles an hour."

To allow that a natural law, capable of creating such tempests, is constantly in action would indeed be highly absurd; but the absurdity here brought to view springs wholly from the monstrous supposition of a body of air "suddenly" or instantaneously transferred a distance of 30°. If we assume it to be transposed at the rate of 20 miles an hour, which is probably what really occurs, then it would take 90 hours to pass over 30°, and the velocity of its westward motion would be but $1\frac{1}{3}$ mile an hour. Mr. Laughton insists much on the great friction of the air; and certainly the air next the ground must be checked by friction; but of the wind in general the friction hardly deserves consideration. The friction attending motion increases in the duplicate ratio of the velocity producing it. Now the wind, which is sensibly felt when moving with a velocity of 5 miles an hour, may attain a velocity of 100 miles, and continue thus for hours in spite of a friction 400 times as great as that with which it began. If there were any truth in Mr. Laughton's statement, that "wind almost instantly assumes the velocity of any point of the earth with which it comes in contact," then the ordinary state of the air would be a dead calm, which is certainly not the case. The air is fortunately almost always in motion, and some wind blows. He tells us that, when philosophers admitted the deflection of wind in consequence of the earth's rotation, they forgot the effect of friction. And surely in writing this he must have forgotten that the long list of the philosophers alluded to includes the names of Halley, Kant, D'Alembert, Sir J. Herschel, and Dove. At the present day philosophers of the greatest eminence maintain that not only currents of air, but the courses of rivers also, are influenced by the rotation of the earth.

In attacking the fundamental principles of meteorology, Mr. Laughton affects to be rigorously exact. He plunges into minute details; and there he misses his way. He finds that the barometer is misnamed, and that philosophers have hitherto erred in supposing that it measures the weight of the atmosphere. "What the barometer does," he says, "is to measure the elastic force of the air. With weight it has nothing whatever to do." To prove this he appeals to the action of air on a barometer in a close vessel. But surely the atmosphere is not a close vessel. The elastic force of air increases with temperature; but the barometer falls in the transition from high to low latitudes, and from winter to summer; that is, it falls as elastic force increases. The barometer is always lower at Calcutta (lat. 22° 33′) than at St. Petersburg or at Ajansk, in lat. 56° 27′ N., on the Bay of Ochotsk; but if it measured the elastic force of the air it would be always 2¾ inches higher at the first than at the last-named of these places. It is a melancholy discovery that Torricelli, Pascal, Boyle, Hooke, Descartes, Huyghens, and indeed all eminent philosophers down to the present day have laboured under a delusion, imagining even that they could measure the height of mountains by means of the barometer. They thought, as Sir J. Herschel has well explained, that it measured the weight of the superincumbent atmosphere. It was especially unfortunate that one who dreamed that he had discovered that "the barometer has nothing whatever to do with the weight of the atmosphere" should have thought fit to write on Physical Geography*.

The same author denies the existence of belts of calm, because, notwithstanding the great friction of the air, on the all-sufficiency of which he elsewhere insists, there is no such thing as a perfect and perpetual calm. But surely the name Belt of Calms implies neither perfection nor perpetuity. He denies, too, the existence of an ascending current between the trades, because nothing is seen to ascend but clouds and vapour ; and, still rigorously exact, he calls in question the meteorological law established by Dr. Hutton, that, when currents of air of different temperatures mix together, the point of saturation is lowered in the mingled mass. He affirms that gases and fluids at different temperatures refuse to mix—a statement that has no foundation. When two volumes of water are thrown together, being swayed only by inertia and internal cohesion, they mix mechanically without any tendency to intimate diffusion. If they differ in temperature, that may allow their separation to be traced, though it does not cause it. In the case of gases a difference of temperature does not in the least degree retard their interpenetration.

But what is the end or purpose of this revolt from principles in which the scientific world has long perfectly acquiesced? It terminates in the conclusion that there are no winds moved by difference of temperature towards the equator, nor are there any returning currents towards the poles, but that the primary and ruling winds are the west winds, from which are derived all others. Whence they come, and how they give birth to east winds, are left wholly unexplained. But here it is necessary to remark that Mr. Laughton, even when dwelling on details, is more minute than accurate. When he speaks of west winds he means to include all winds which have any westing in them. Yet it is evident that N.W. and S.W. winds must come from differ-

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* It is a curious fact in the history of Physical Science, that in 1872 a book denying that the barometer measures the weight of the atmosphere, was laid before a Section of the British Association with the special commendation of the President.

ent sources. He thinks also that, since the prevalent wind in Egypt veers from N.W. to N.E., the latter (further south the N.E. monsoon) really belongs to the west-wind family; and it bears, he tells us, to Abessinia the rains which fill the rivers of that country and cause the floods of the Nile. Now this is an unpardonable mistake. The N.E. monsoons shed the scanty rains of winter on the barren sea-coast of Abessinia, rising no higher than 4000 feet. But the fertile interior and high land of Abessinia owe their rains entirely to the S.E. wind. He also ventures to assert that the N.E. monsoon of India is the N.W. wind deflected, how or why it is impossible to understand.

He dwells much on the violence and superior strength of west winds; for he seems to suppose that the primary winds must necessarily be the strongest. But the west winds prevailing in the zones of changeable winds meet with resistance; and resistance begets violence. Winds from all quarters blow in St. George's Channel with a force entitling them to be called primary. That the west winds are in general stronger than the trades or east winds, from which they are believed to proceed, is not only true but is a necessary consequence of their derivation; for being a returning current from the equator in the upper region of the atmosphere, they carry with them to some extent the rotatory velocity of the equator to a higher latitude. The strength of the trade-winds blowing from the S.E. may be estimated by the distance of their sources (say lat. 30°) from the equator. The difference between the rotatory velocity of the latter line and that of the 30th parallel gives the increase of the returning wind's eastward velocity. The upper wind, less dense and further from the surface, is less checked by friction; and when it reaches the surface as a west wind it has the much greater eastward velocity due to the difference between the equator and the 40th parallel. Since the strongest trades are the S.E. winds on the western side of the Atlantic, which are stiff breezes or nearly gales, we should expect to find these gales increased by transference to a higher latitude, somewhere about the 50th parallel, between the South Atlantic and Australia; and it is exactly there that Mr. Laughton points out those primary west winds for the strength of which he finds it so hard to ccount. Were his history of the winds quite correct, yet his xplanation of their origin is wholly unintelligible. He seems ever to be aware of the dark unfathomable gap which lies beween his premisses and his conclusions. No account of the vest wind which leaves the east wind and some others unexlained can be satisfactory.

CHAPTER XIV.

Cyclones.—Whirlwinds variously generated.—Conflagration.—Sand-pillars.—Waterspouts.—Trombes.—Tornadoes.—Hurricanes—their Course in the West Indies—near Mauritius—Bay of Bengal—Chinese seas—their Diameter, Speed, &c.—not strictly circular—Violence—Advantages to be derived from Knowledge of their Nature—Explanations of Peltier, Dove, &c.—their probable Origin.

Were the globe uniformly covered with water, it would be girdled with a complete zone of constant and regular winds blowing towards the equator, and with equally constant returning winds going off from the equator towards the poles, though turning eastward before reaching the polar circle, the whole system annually shifting place a few degrees by following the sun's declination. But such uniformity is prevented by the unequal distribution of land and sea; and over about a third of the earth's circumference, chiefly within the tropics, the constant winds give way to alternating winds, changing with the season.

But originating within the limits or in the immediate neighbourhood of the regular winds, there is a class of a different character, which, from their singularity and extreme violence, call for special notice. Sailors dread a gale—that is, a furious wind blowing in a straight line or constant direction. But it is now well known that the most dangerous winds do not blow in a straight line, but revolve as whirlwinds round a centre, adding continual change to violence and involving in the storm a wide area from which it is difficult to escape. Whirlwinds occur in various forms and of very different scales; yet in combining a revolving with a progressive motion they closely resemble each other. The phenomena presented by them are extremely obscure; and as these pages cannot afford room for discussing them in detail, they shall be here grouped together in such a manner as to show, with the peculiarities of each kind, what they have in common. An attempt shall also be made to offer such an explanation of their origin as may be more or less applicable to all, their striking differences and the modifications of action thence arising being at the same time pointed out.

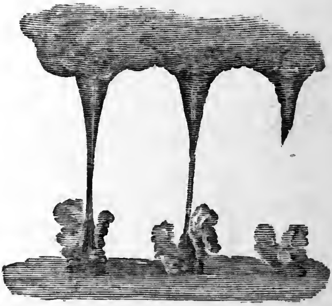
The chief vorticose phenomena of the atmosphere are whirlwinds produced by conflagration, whirls of dust or sand, waterspouts, trombes, tornadoes, and cyclones. When an extensive thicket of dry reeds or brambles is set on fire, there is presently seen, over every lively flame, a pillar of smoke, ascending in a manifestly spiral course, and spreading out above in the form of a funnel. Sometimes, while the dense smoke and embers are all carried up, the lowest part of the column remains clear and unmarked by any visible outline, though the course of the air is still shown by leaves and other light bodies ascending with it, while the funnel-shaped cloud still hangs overhead (fig. 75). Jets of smoke from volcanoes show the same tendency to revolve. In these cases there can be no doubt as to the cause of the movement. The heat gives rise to an ascending current. The ascent is easier by an nclined plane, and as the inflowing air can hardly fail to be superior in strength in some one direction, that determines, in the first instance, he inclination of the ascending current; but he lateral resistance to this being greater on he outer and cooler side than on the side of the flame and uprising column of heated air, it bends towards the latter and he inclined plane becomes a spiral path. The smoke as it ascends grows cool and sluggish, and yields more to the centrifugal tendency. Consequently it accumulates, and, spreading out, passes from the form of a spiral column to that of a widenng funnel, and lastly to that of a shapeless cloud.

Fig. 75.

Pillars of sand or dust are frequent in North-western India, in he deserts of Arabia and Africa—wherever, in short, a dry and heated surface of loose soil lies bare of vegetation. They occur most frequently in calm and sultry weather. Here, again, the ause is manifest. When any spot of ground becomes excesively heated and the air above it ascends, an influx takes place o it from all sides, the heated air being ready to escape by any hannel opened; but the influx not being perfectly equal on all sides results in a gyrating motion, which is visible in the sand or dust raised by the air. These sand-pillars in India often attain a diameter of 15 or 18 feet, and seem to reach the clouds. When they run together they sometimes cover an area of some hundreds of yards in extent. They advance in the direction of the prevailing wind, but rarely last long. The clouds of dust raised by them in the atmosphere often fall at a great distance. Showers of sand from the African Sahra frequently darken the sky at Madeira.

Waterspouts are among the most singular phenomena in nature. They are columns of water or opaque vapour rising from the sea, and joined above by a cloud meeting it in the form of an inverted cone. The water at its base is in violent agitation, as if boiling; and the column, while moving on, revolves with a violence dangerous even to the largest ships (fig. 76). Though often of small dimensions, some have been observed with an estimated diameter of 200 feet and a height of 1500 or 2000 feet. The column is at times apparently incomplete, the portion rising from the sea failing to meet that descending from the cloud, or either of these parts may be wanting. The column of water can be accounted for only by supposing an eddy in the atmosphere, which, as the air is driven outward by centrifugal force, creates a vacuum in the axis of motion, into which the water rises to a certain height. Above that height the opaque or visible continuation must be formed of vapour ascending from below, or descending from the cloud above. Few waterspouts stand still; in general they have a progressive motion, with a velocity exceeding half a mile in a minute. Instances are not wanting of waterspouts advancing from the sea upon the land, and there running a destructive course of some miles. Like sand-pillars, waterspouts are often seen together in considerable

Fig. 76.

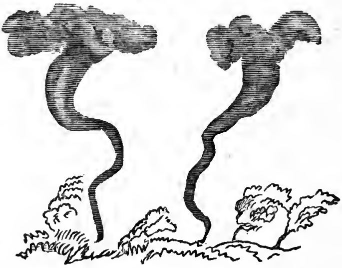


numbers. They revolve, as the former also, indifferently from left to right, or from right to left, and even when close together revolve in different directions.

But still more extraordinary are the phenomena of the same kind which occur on land. The name waterspout, given to them also, does not describe, much less does it distinguish them. The French name *Trombe* more fitly embraces both kinds, and shall be here adopted for that which does not seem to be essentially connected with the sea. It does not appear that the birth and early growth of a trombe has ever been observed.

In general trombes make their appearance in a calm atmosphere with surprising suddenness and perfectly developed. Wonderful and portentous when first seen, they often exceed waterspouts in magnitude, and, rushing forward, spread destruction over a tract exceeding 1000 feet in breadth (fig. 77). They tear up trees, unroof or throw down houses, overturn and scatter every thing in their path, accompanied by floods of rain, with destructive lightning and fireballs. Most trombes as well as waterspouts have manifestly a violent rotatory motion, marking them with spiral lines. Water generally ascends in them, and they dry up the ponds over which they pass. But in some cases water seems to descend through them. The air near the ground rushes to them violently from all sides, and within the column is a force tending upwards. Men and other heavy objects caught in the whirl are lifted from the ground and flung to a distance. In August 1845 a trombe, within a few miles of Rouen, tore up in a few minutes 180 large trees, and destroyed some buildings, the fragments of which fell half an hour later near Dieppe, at a distance of 16 miles. These phenomena are always attended by a fall of the mercury in the barometer. Heavy rain rarely fails in their track, but it is sometimes replaced by hail or snow. Among their other singularities are mentioned, besides a strange whirring noise, a peculiar smell

Fig. 77.



and a faint luminosity at the lower end of the trombe. These latter may be the effects of electrical excitement.

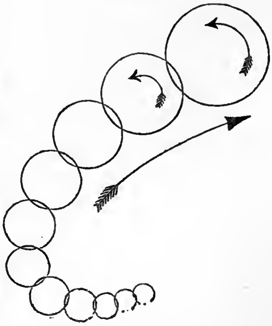
The whirlwinds so far described have all a visible centre. A column of smoke, dust, water or vapour marks the position of the axis round which the wind revolves. That a very violent influx of air from all sides takes place to the revolving column is clearly proved. The position of the trees laid low, of the growing crops levelled in the path of the trombe, all point out the direction of the destroying force. But when we proceed to consider the whirlwinds of a higher class and greater magnitude (as, for example, the tornadoes, so common at the equator and in North America) the phenomenon becomes more aerial, and we miss the opaque, visible axis of the storm, though all the terrors that usually surround it still remain. The average breadth of the tornado (so called by the Spaniards from *tornar*, to turn) is about 750 yards, its height a mile, the mean length of its course 42 miles, and its speed about 37 miles an hour. But one of much greater dimensions has been recorded which ran 800 miles. It revolves about a vertical axis against the sun, or from right to left in the northern hemisphere. The progressive motion of the American tornado is generally a little to the north of east. These whirlwinds occur chiefly by day, and only in warm weather. They are always attended by rain and lightning, and the fury with which they revolve is indescribable. Birds are stripped of their feathers and killed by them ; small trees or planks carried off by them fall from the clouds at a distance perhaps of 6 or 8 miles. It is related that a stem of bamboo blown by a tornado penetrated a five-foot wall, which a shot from a six-pounder could hardly have done. A tornado with a visible column of vapour, sweeping over Ohio in January 1854, prostrated 50,000 trees in half an hour. Great loss of life is due to them, and greater destruction of habitations ; but they are as brief as they are destructive ; they ruin instantaneously and pass on.

Hurricanes differ from tornadoes only by their greater magnitude and continuance, involving a much greater area, with perhaps some abatement of violence. It was long suspected that the most violent storms of wind move in a curvilinear path. In 1801 this opinion was advocated by Colonel Capper ; yet a quarter of a century elapsed before it drew attention. At the present day it seems to be fully established that hurricanes (or, as they are now called, cyclones) are winds revolving round a centre, which at the same time advances. Having once attracted the observation of meteorologists and skilful navigators, they have lost much of their mysteriousness and danger, and we can now describe their peculiarities from the reports of experienced seamen.

Cyclones originate chiefly in warm seas not far from the tropics, but never at or near the equator. There are some regions of ocean in which they are particularly frequent; these are:—1st, the western side of the North-Atlantic Ocean; 2ndly, the Southern Ocean near Mauritius; 3rdly, the seas about the Indian peninsula; and 4thly, the Chinese seas. But though more frequent in particular regions, they are not strictly confined to any. The mariner knows tha tin some situations (as, for example, near the Cape-Verde Isles) he is extremely liable to attacks of bad weather; and that few spots on the face of the globe are thought to be exempt from such visitations. In truth, cyclones seem to be occasionally met with everywhere, except near the equator and in the polar seas. They have been experienced in the Mediterranean and the Black Sea; but it does not lie within the scope of this work to follow all the tracks of cyclones or to discover their haunts.

In the Northern Atlantic the cyclones seem to start from the middle of the ocean, between the 10th and 12th parallels of latitude. Their first course is W.N.W. to the West-Indian seas or the Gulf of Mexico; but on arriving at the latitude in which the S.E. trade-wind is no longer felt, or perhaps where the S.W. up trade begins to prevail, they wheel round at right angles to their former course and run to the N. or N.W., at the same time greatly increasing in extent and progressive speed (fig, 78). This fresh development is obvi-

Fig. 78.



ously due to the circumstance that the storm now falling in with the Gulf-stream is aided both by the oceanic and prevalent atmospheric currents. But the danger of the storm lies in the fury of its revolving motion, and not in the speed of its advance. When once above the northern tropic, the cyclone spreads out to a diameter of 1000 or more miles, at the same time becoming much less violent than when raging in the West-Indian seas with a breadth of only 300 miles. Cyclones following the course just described have occasionally advanced as far as Norway, in the 70th parallel of latitude. These cyclones revolve in the northern hemisphere from E., by N. to W., or contrary to the hands of a watch. In the southern hemisphere their motion is in the contrary direction, or N., E., S., W.

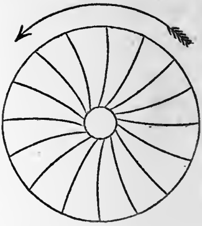
The cyclones that arise in the southern hemisphere near Mauritius are the exact counterparts of those just described. They proceed W.S.W. till they come to the limits of the N.E. wind and enter the domain of the S.W. monsoon. They then change their course and, running with the latter wind, increase in extent and progressive speed. In the Bay of Bengal the hurricanes advance from the Andaman Islands north-westwards to the mouths of the Ganges and Burrampooter, spreading devastation over the adjoining region, not more by the fury of the wind than by heaping up the waters of those great rivers and thus causing extensive inundations. In the Chinese seas the cyclones, there called tyfoons, proceed in summer westward from some point south of east, varying, however, as the season advances. In autumn their course is from east of north to west of south. Their rate of progress is estimated to be from 7 to 24 miles an hour. The destructive storms in the Bay of Bengal move on slowly, at a rate of from 3 to 15 miles an hour.

The approach of a cyclone is announced by a dense mass of black clouds appearing on the horizon. The storm being impeded by contact with the earth leans forward above and is preceded by the canopy of clouds belonging to it, which extend far beyond it on all sides, especially in front. As these advance the barometer falls ; then comes the wind in tremendous gusts, and veering in a manner that shows the revolution of the storm. This is always against the sun—that is to say, it is, in the northern hemisphere, from the right hand to the left of one who stands facing the equator ; in the southern hemisphere from the left to the right under like conditions. Near the centre of the cyclone the turmoil ceases. A respite of short duration takes place with perhaps a clear sky. Presently the wind returns with fresh fury, from the point opposite to that last experienced, and half of the storm-circle remains still to be encountered. At the centre the barometer falls to its lowest point, which may be more than 2 inches below its height outside of the cyclone.

The diameter of a cyclone is said to be in general from 50 to 300 miles ; but sometimes, and especially in high latitudes, for it spreads as it advances (fig. 78), it extends to 1000 or even 1500 miles. The speed with which the storm advances, at first 15 or 20 miles an hour, increases to 50 miles in high latitudes ; but its velocity of rotation at the circumference probably exceeds 90 miles an hour ; further in the gusts are said to be still more violent. As to its height, some have estimated the elevation of the storm-clouds to be 10 miles above the earth's surface ; more sober calculators bring them down to 4 miles. These conjectures refer to the upper edge of the pile of clouds on the horizon. But far below these, or at the height of from 500 to 2500 feet, the clouds called the storm-scud are thrown off from all sides. Next to the extreme violence of the cyclone, nothing about it is so remarkable as the prodigious fall of rain that attends it, amounting on the coast of Malabar to 10 inches in a day, or nearly one third of the average annual rainfall of England. Nor is this surprising, since the vapours of a wide circle of agitated ocean, perhaps 300 miles in diameter, are swept off with the greatest rapidity and collected in a pile of clouds of still greater extent.

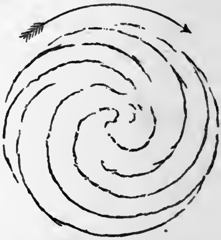
Among the most attractive of the early attempts to explain the nature and origin of hurricanes must be placed that of Mr. Espy, who supposed the storm to be occasioned by an inrush of winds from all sides to a vacuum left by a heated and ascending column of air. But he did not account for the revolution of the storm. To supply this omission, it was suggested by Mr. Taylor that the inflowing winds being deflected in their passage, all struck the central column obliquely, and thus made it revolve (fig. 79).

Fig. 79.



But, in truth, the whole storm revolves, and not merely the central column. Nor can it be admitted that the centripetal winds miss their mark, owing to deflection, since being aspirated winds they begin at the centre and are propagated backwards. Finally, those winds blowing from all quarters towards the centre are not in fact found in a cyclone, which, however wide may be its extension, is one whirling wind revolving round a centre.

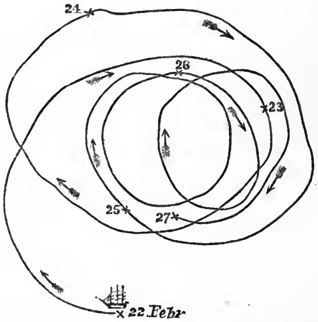
Fig. 80.



In speaking of cyclones or of whirlwinds in general, it is ordinarily assumed, for the sake of simplicity, that the wind revolves in a circle; but in truth it everywhere makes an angle of from 6 to 19 degrees with the tangent, and thus tends to the centre in a spiral course (fig. 80). But this irregularity of curvature is so slight, so variable, and so hard to be ascertained, that it is more expedient to consider the cyclone as circular. The rush of air from all sides to the centre would be utterly incompatible with the fall of the barometer if the spiral current did not at the same time rise and unite in one screw-like ascending current. Within the storm the gusts of wind grow more violent towards the centre, because they carry the velocity of the circumference into smaller circuits. At the centre the violence abates more or less for a short time. Birds of different kinds, butterflies, moths, &c. are there found together, driven in by the wind. As the revolution of the storm is not perfectly circular, so the collective figure of the cyclone is not a circle, but rather an irregular oval with that side most developed on which the prevailing wind favours the revolving movement. The densest clouds, the heaviest rain, and fiercest wind are usually in the front of the cyclone in the direction of warmth and moisture, which latter, of course, is to be measured by saturation. Owing to the irregular vorticose motions of the whirlwind, it is evident that seamen caught by it find it difficult to determine with exactness the curvature of its course, or whether it be circular, spiral, or elliptic. It implies, therefore, no disparagement of their testimony to infer that what seem to them to be circular currents are really spiral. The motion of any point in a cyclone is compounded of the revolving and progressive motions of the storm, which combine to form an irregular spiral.

In May 1863 the ship 'Earl Dalhousie' scudded, at the rate of from 10 to 13 knots an hour, three times round the centre of a cyclone; and off Mauritius the 'Charles Heddle' scudded round and round for five days, so that after sailing 1300 miles she was but 360 miles from her starting-point (fig. 81). These examples do not prove that the wind did not blow in closed circles, but they show clearly enough that cyclones are not composed of winds blowing in straight lines from all quarters to one point.

Fig. 81.

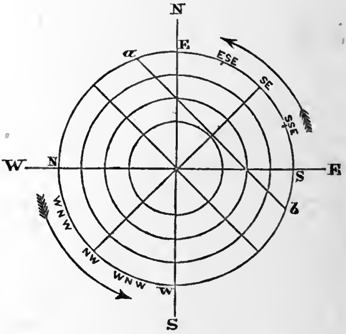


The violent and destructive force of hurricanes form a theme too copious and at the same time too foreign from the object of this volume to be here dwelt on. We learn from the air-gun the strength which air may acquire from compression; but we cannot the less wonder at seeing it exercise, without compulsion and in the free atmosphere, an apparently equal force. We read of heavy guns (24-pounders), moved some distance by the winds, of large buildings lifted from their foundations, of houses with their inhabitants blown from a distance into the sea, of sea-shores covered with birds and fish crushed by the storm, of large ships thrown from deep water high up on the land. The history of hurricanes is filled with prodigy; and those who witness prodigies are perhaps unable to curb imagination; for it is hard to believe that thunder is not audible while the hurricane roars, and that the wind is luminous or gleams at every fresh gust as if with faint lightning. As the wind blows from all quarters within the cyclone, the result is a very agitated cross sea, with an unusual quantity of broken water and flying spray, which adds to the seaman's troubles.

Though little reliance can be placed on the statistics of the wind, and no valuable information is imparted by stating how many cubic miles of air or of water enter or proceed from a cyclone, yet it may be mentioned, as a curiosity of calculation, that the force exerted by the hurricane which laid waste a part of Cuba for three days (from the 5th to the 7th of October, 1844) is computed to have equalled the power of 473,500,000 horses, or about 15 times all the power of horses, men, and machinery that the whole earth could furnish in the same time.

The danger attending revolving storms has been of late years much diminished by the study of their peculiar character, and the light thereby thrown on their movements. The mariner's chief care must be to avoid the centre of the storm, and perhaps while doing so he may be able to avail himself of the portion of its circumference directed to his destination. If we suppose the wind in a cyclone to revolve in a circle, then its direction at any point will be at right angles to a line drawn to the centre of the storm. Due north from that centre it will (in the northern hemisphere) blow from the east; north-east of it, form the south-east, &c. Consequently a seaman crossing a cyclone, as from *a* to *b* (fig. 82), and aware how it revolves, may learn, from the continual veering of the wind as he advances, the direction in which lies the centre, which he must carefully avoid. If the wind does not veer, then he goes directly to the centre, a danger of which his barometer also will give him warning. If his course be not directed to the centre, the wind veers at every step. The particular rules by which a seaman may judge of his position in a cyclone are fully given by Professor Dove in his work on the Laws of Storms; while an ample history of cyclones, with their nature practically considered from

Fig. 82.



the sailor's point of view, may be found in the Sailor's Hornbook of Mr. Piddington.

Towards the end of the last century, and in an age of philosophy, Peltier could find no better explanation of the phenomena of trombes and waterspouts than the mysterious agency of electricity. In the cyclone (a phenomenon of the same kind, but on a much greater scale) the whirlwind has so far outgrown the accompanying atmospheric disturbances that these lose their relative importance ; and none of the writers on revolving storms at the present day, except, we believe, Mr. Piddington, is disposed to ascribe causation to the electricity that attends any violent commotion of the atmosphere. Professor Dove, of Berlin, the highest authority in questions of meteorology, suggests that cyclones arise from the disturbance of the lower currents of the atmosphere, by the descent of opposite currents from above. The invading body of air striking the invaded, in the northern hemisphere on the right, he says, compels it to turn to the left, and continuing to press forward causes a complete gyration, which, while constantly urged from above, is collectively carried on by the lower current. This account of the origin of cyclones is certainly more reasonable than that previously in vogue, which referred them to something mysterious and inexplicable ; yet it is far from satisfactory, and leaves untouched much that needs elucidation. It is not easy to understand why an extraordinary influx of air from above should cause depression of the barometer, the invariable forerunner and attendant of hurricanes. Then the regularity with which they revolve, in a certain direction or against the sun in both hemispheres, is not sufficiently accounted for when referred to the tumultuous agency of furious winds. Finally, no force can give birth to a force greater than itself ; it cannot of itself generate a motion of unabated continuance or increasing velocity. Now the cyclone, after running some distance in obedience to its first impulse, wheels round at right angles to its first direction, and then, with increased magnitude and velocity, travels a distance of perhaps 1000 miles. It is obvious that in this case the first impulse is reinforced by another, apparently stronger, generated within the storm itself, and thus lengthening its duration.

Let us now endeavour to trace the development of the cyclone, looking at the general characters of the whole class of phenomena with which it is connected. Revolving storms and whirlwinds of every kind make their appearance chiefly in warm climates, in the hot and humid season of the year and in calm weather. The atmosphere is then most liable to be in an unstable condition. The lowest stratum being the most heated is often lighter than that above it, the calm air on a level surface accumulating heat below faster than it parts with it above by intermixture. In this case any local disturbance, as the heat of a black stone on land or a gathering of vapour over the sea, may break the stillness and cause an ascending column of air. This is instantly replaced by an influx from all sides ; and as there can hardly fail to be some inequality in these uniting currents, some one of them will preponderate. Consequently the ascending column soon takes a spiral path round the vertical line ; and as the warm air continues to flow up while the cold runs down, rapid currents fill the spiral path. If there be vapour in this current it condenses as it ascends ; and heat being thus disengaged, gives fresh energy to the upward movement and adds to the increasing dilatation of the column, though the continued action of centrifugal force might suffice to explain the spreading of the revolving mass. Hence it is evident why the waterspout takes in the clouds the form of an inverted cone with the apex turned downwards. In the waterspout, trombe, and small tornado, the rush of air to the base of the visible column and the current ascending within it, to disperse above, are easily observed. A communication is manifestly established between the air on the ground and the atmosphere higher up, the process beginning with heat and ending with coolness. The local origin of the phenomenon and the nature of the errand, with the completion of which it terminates, are clearly ascertained.

But perhaps it may be said that there is little resemblance between a waterspout and a hurricane, and that the latter, with a diameter of 100 miles or more, cannot be supposed to originate in any trivial local disturbance. Certainly, in form and dimensions, the fully developed cyclone has little in common with the local eddy of wind ; yet it must be remembered that all classes of vorticose phenomena vary in magnitude. All begin small, the largest of each class nevertheless attaining the dimensions with which the next class commences. While differing in size they may agree in constitution ; and differences apparently great may arise between them merely from unequal development. Suppose a communication in a vertical line to be suddenly opened between the warm air at the surface of the ground and the air 300 feet higher up and 20° cooler, a rapid ascent of air would take place, and the tornado produced by it would attain dimensions strictly limited by the atmospheric areas and the amount of inequality calling for adjustment. But place this tornado on a warm ocean, and see the transformation it will undergo. The rush of wind at the surface of the sea which begins it will be accompanied by abundant vapour. This vapour, as it rises, being condensed, will give out heat ; this quickens the current, gives fresh energy and enlarged dimensions to the whirling column. As the diameter of the tornado increases, the area involved by it and the vapour swept into it increase in a duplicate ratio. To the supply of that vapour there is no near limit, while in the heat disengaged from it we find a power, originating within the whirlwind itself, which ensures its full development and lends it vitality, so that it can travel even from the tropic to the polar circle.

In one respect waterspouts, tornadoes, and all whirlwinds of a minor class differ from cyclones, for they revolve indifferently from left to right or from right to left. Their revolution is determined by the predominance of wind from one side, and that generally depends on the configuration of the surface. But cyclones are removed by their magnitude from the absolute sway of local influence. Covering an extensive area, they obey the deflecting impulse due to the earth's rotation. As that increases with distance from the equator, it must always predominate on the polar side of the cyclone, and thus determines its revolution, which, as if due to the pressure of a polar wind on the north and an equatorial wind on the south, is always from right to left in the northern hemisphere. Though the resemblance of hurricanes or cyclones to waterspouts and tornadoes is not obvious to the senses, their similarity may be discovered by a little attentive consideration. In the minor phenomenon we observe a rush of air to the base of the column ; we see proofs of its ascent and of its diffusion at the summit. Now in the cyclone the hurricane-wind is the inrushing air ; its ascent in the centre of the storm is proved by the barometer, and its diffusion above is seen in the piles of clouds evolved from the storm and overhanging it to a great extent around. The quantity of air which has rushed up may be estimated from the quantity of vapour spread in the clouds or falling in torrents, and which constitutes the animating principle of cyclones.

It may be conjectured that for the creation of a violent revolving storm no condition is more important than the close approach of two currents of air of widely different temperatures, the cold and heavy above, the warm and light below. This is exemplified on the eastern side of Armenia, where elevated plains abruptly terminate in deep valleys. As soon as the cold winds from the Caucasus reach the edge of the tableland, hurricanes and hailstorms desolate the low country. Though cyclones may occur at all seasons, they are far most frequent in August and September, when warm currents of air and vapour probably reach the greatest altitude, and when the summer atmosphere of one hemisphere and the winter atmosphere of the other are about to change places.

Although whirlwinds and cyclones are generally regarded as peculiar to the warm zones of the earth, in which they are constantly met with, there is reason to believe that they occur in all climates, and more frequently than is supposed. The Buran, or snow-storm of Russia and Siberia, appears to be a cyclone, and to spring, as in warm climates, from difference of temperature between aerial currents. Two kinds of Buran are recognized, viz. the one from above, the other from below. In the former, the wind is accompanied by a fall of snow ; in the latter, the snow is swept off the ground by the stormy wind. The snow, gathered in thick masses, is whirled about in such disorder as totally to distract and bewilder all overtaken by the storm, and numbers perish close to their own doors. Yet it is not the driving snow and darkness that make the Buran so formidable, but the sudden change of temperature that attends it. The wind that descends with such fury at the same time lowers the temperature perhaps 20°. Reindeer harnessed in the sledge are frozen ; and the intense cold, which is endurable in a calm atmosphere, becomes quickly fatal when borne by violent blasts of wind. It is related that in the winter of 1827–28, a Kirghis Horde, on the left bank of the Volga, lost by a Buran 280,500 horses, 10,000 camels, 74,450 horned cattle, and 1,012,000 sheep. On the Russian borders these storms most frequently occur in the middle of winter ; further east in Siberia they are more likely to rage about the equinoxes or at the changes of the season. A great Buran seems to be a series of whirlwinds. It ravages the Tundras and open naked plains, but never approaches forests.

CHAPTER XV.

Clouds.—Lightness of Vapour—Tendency to regular Structure.—Howard's Nomenclature—Cirrus—Cumulus—Stratus.—Vain attempts to multiply Distinctions.—The support of the Clouds.—The Vesicular Theory.—Viscosity.—Clouds merely transient.—Proofs of some Stability.—Cumuli in dry weather.—Clouds travel far.—The Globular Theory justified.—Why Clouds do not exhibit the prismatic colours.

Water has a visible inclination to imbibe heat and, combined with it, to evaporate or go off in the gaseous form as invisible vapour. That it is urged to this change by chemical affinity or by an innate elasticity hardly held in check by the pressure of the atmosphere, may be suspected from the fact that evaporation takes place at all temperatures, increasing, however, with the supply of heat and the diminution of pressure. Aqueous vapour in the gaseous form, when once constituted and mixed with permanent gases, acquires in some degree the stability of a true gas, and retains the gaseous form at a temperature much lower than that necessary in the first instance for its formation.

Aqueous vapour, being lighter than air in the ratio of ·625 to 1·000, ascends at once under the control of two opposite influences—namely, heat, which gives it life and elasticity, and atmospheric pressure, which restrains it. As it ascends, the surrounding temperature and also the pressure diminish; and there is reason to believe that in the lower regions of the atmosphere the decrease of pressure fully counterbalances the loss of temperature that attends increased elevation. The gaseous vapour that rises under a clear sky finds the atmosphere drier the higher it ascends, and being rapidly diffused, remains invisible at a great elevation. It forms no cloud nor discernible haze; yet an experienced eye can generally distinguish, even in a perfectly cloudless sky, between a humid and a dry atmosphere. The pure intense blue of the latter is rendered pale by humidity. In the one case we see a canopy of deep blue strongly illuminated; in the other the colour and effulgence seem to be softened by a delicate white veil. On the evening of a warm summer's day the vapour descends; the blue sky grows paler and less luminous, till at length the indistinct haze gathers into the perfectly defined form of clouds which reflect the rays of the setting sun. This we believe to be the ordinary process of cloud formation. Vapour ascends in its transparent state to the higher regions of the atmosphere, and thence again it descends, charged with the electricity of those regions, to form clouds. These are not transparent, because the vapour in sinking undergoes a change of state; it changes into minute molecules of fluid; and since air and water have different refractive powers, light cannot pass through a cloud formed of their particles mixed together. Clouds, however, do sometimes rise directly from the ground. Morning mists in spring may be often observed as they ascend, till at a certain level they go off as rounded clouds or cumuli. But these probably break up and disappear, or if not, they soon return to their former condition, and fall as nocturnal mists. Clouds and mists are essentially the same; though in the measure and stability of the power that supports them they may possibly differ.

Clouds often appear shapeless and confused, spread out in the heavens like a screen, or rolling along without order; but very frequently they manifest a tendency to regularity of shape and arrangement, and have perhaps always more of this than is visible from below. They seem to be influenced by an attracting or aggregating principle, which, uniformly diffused throughout, inclines them in calm weather to collect in similar groups, at equal distances and in straight lines. As they gather thickly, the intervals between the groups are filled up, and all seem to melt into a single mass, although from above they might present the appearance of a series of ridges. In dispersing, they offer the same indications of original structure. As the cloud grows thin and breaks up, the widespread uniform mass changes to a series of wave-like lines, often divided so as to form a mottled sky not without symmetry. This coherence of a body floating in the air implies some inherent principle of attraction and repulsion, feeble and often concealed. Lines of clouds lie generally at right angles to the direction of the wind, and in this case they are often broken into equal patches; but sometimes, after high winds, clouds may be seen apparently swept and drawn out in the direction of the wind. A narrow line of clouds drawn completely across the sky may occasionally be observed marking the contact of the N.E. and S.W. winds. Clouds in general are level at their under surface, while above they are irregularly piled up, and seen from a balloon present the appearance of hills and mountains pressed together. The general height of the clouds in fine weather is, in middle latitudes, from 4000 to 9000 feet. They are higher in summer than in winter. When precipitation takes place they sink, and rain generally falls in temperate latitudes from the height of from 1200 to 2500 feet. We know of no limit to the thickness of the clouds. When Messrs. Bixio and Barral ascended in a balloon from Paris in 1850, they passed through a cloud two miles thick. But that was probably unusual. The occasionally extreme darkness of the clouds may be caused by their thickness; but it is more frequently due to a number of strata floating at different heights and intercepting the light from those beneath.

In attempting to describe the clouds, it is impossible to dispense with the simple and expressive nomenclature devised for them by Mr. Luke Howard. He distinguished in them three predominant forms, viz. the Cirrus, the Cumulus, and the Stratus; that is to say, the combed or curried, the heaped or rolled up, and the strewed or spread out cloud. The cirrus is the delicate feather-like, perfectly white cloud, commonly called Mare's Tail, which is seen at great heights, and therefore rarely in bad weather. It has a filamentous appearance, and the regular arrangement of its filaments justifies the application to it of the epithet "combed." This regularity has been ascribed by some to electricity, by others to wind, which latter, however, is more likely to cause irregularity or to destroy a delicate texture. It might, however, be considered in many cases as the effect of atmospheric vibration or undulation, which throws the condensed light vapour into lines, just as sea-weed is ranged in parallel lines by the waves of a summer sea. The cirrus belongs to the uppermost current, or, in our quarter of the globe, generally to the S.W. wind. Its stem very often extends from S.W. to N.E., while its petals lie at right angles to that direction. From the great height at which cirrus is sometimes seen, 20,000 to 30,000, or even, in low latitudes, 40,000 feet; and from the optical phenomena, coloured haloes, parhelia, &c. in which it takes a part, there is reason to believe that the vapour composing it must be at times congealed, or that the cloud is composed of minute icicles.

The cumulus or cloud-heap is in fine weather the most frequent as well as the most cheerful and attractive form of cloud. Its base is perfectly level, but above it is piled up irregularly, exhibiting, in proportion as the weather is settled, rounded and firmly defined edges. The upper borders of the cumulus reflect the sun's light in great abundance, forming in fact the most agreeably luminous portions of the summer sky, while the parts averted from the sun wear a soft purplish neutral tint. The cirrus is under ordinary circumstances uniformly white and colourless; but the cumulus, with great variety of tint, is, when irradiated by the sun, not merely white, but extremely splendid.

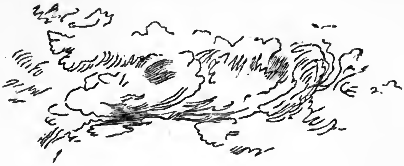
The stratus is the cloud drawn at times like a curtain over the whole sky, so as completely to shut out the bright light of heaven. More frequently it lies very low, and is always featureless and gloomy. Of the numerous subvarieties of clouds, combining in a greater or less degree the characteristics of those already mentioned, it will be sufficient here to mention the cirrocumulus and the cirrostratus, or the mottled and mackerel clouds, in which the ordinary cumulus and stratus exhibit at a lower level rude imitations of the symmetrical arrangement that distinguishes the cirrus in the calm of the upper region. The nimbus or rain-cloud (that is to say, the cloud in the state of dissolution) naturally ends the list. Its characteristic is that it touches the ground. It is a stratus falling and ceasing to exist as a cloud.

Some attempts have been made to improve our knowledge of the clouds by an elaborate and complex classification of them, in which every peculiarity would be regarded as a specific difference. But no advance towards accuracy can be made by multiplying distinctions where there exists no broad difference. The various classes of clouds pass one into the other by insensible degrees. Every possible modification of cloud, from the cirrus to the nimbus, may be seen in the heavens, and few have a prominency that demands particular attention. The intrinsic atomic force which collects vapour and distributes it, shows its power most perfectly in the upper regions, where the medium is thin, the aqueous particles light, and calm prevails. Hence the cirrus is always and uniformly regular. Lower down in a denser medium clouds gather in larger masses ; but as rocks examined with the microscope are often found to be formed of minute crystals, so perhaps thick clouds may be composed of masses of cirri rolled together, or, more strictly, some regularity of structure may lie hidden in the apparently confused heap. In the region of winds and the commotions caused by currents ascending from the heated surface of the earth, regularity of form and symmetrical disposition are but rarely seen in the clouds, and never uniform throughout. But the vapour-collecting attraction, for which we have no name, is still present, though overpowered in the thick cloud ; and those who look to the clouds for indications of change of weather, ought to be able not merely to recognize the presence of that principle, but also to estimate its relative strength. Little is to be learned at any time from the actual state of the clouds ; but the change they are undergoing is always instructive. Observations should therefore be directed to ascertain whether they are gaining in compactness and self-sustaining power, or relaxing and tending towards dissolution. The cumulus in fine weather flies at a considerable height, varies little in size, assumes a spherical figure, with firmly defined and clean edges (fig. 83). If clouds of this class are seen of very different sizes, breaking asunder or joining together, with torn or fringed edges, and flattening as if through loss of cohesion, then they are about to be converted into stratus or nimbus, and to be precipitated as rain (fig. 84).

Fig. 83.

Gaseous vapour may be reduced by pressure to the liquid or opaque form without precipitation. Fog is cloud on the ground

Fig. 84.



and bearing the pressure of the whole atmosphere; yet it is dry and highly electric. On sea-coasts it is often observed that the air becomes thick or foggy about the time of high tide. This probably arises from the pressure exercised on the base of the atmosphere by the rise of the water. Though a rise of 10 or 20 feet can have no appreciable effect on the atmosphere, yet it may perceptibly affect its lowest stratum, which is most loaded with moisture, and in which alone the change in question has been observed.

It is impossible to fix one's attention on the clouds without being led to inquire how they are supported. Aqueous vapour in the gaseous state is lighter than air, and therefore ascends. It is then transparent; but when it sinks and becomes opaque in the cloud, it is no longer gaseous but fluid, and therefore much heavier than air. How, then, is it sustained and enabled to float in an apparently compact mass at a certain level? The consideration of this question is heedlessly passed over by some meteorologists, while others try to evade its difficulties by subtle rhetoric. It is very generally assumed that the fluid particles of mist, fog, or rain are vesicles or minute bubbles, internally filled with and buoyed up by vapour. These vesicles are rarely visible to the naked eye, but may be easily examined with a microscope. Examination, however, affords no proof of their hollowness or vesicular structure, which is evidently assumed as the only means of accounting either for their buoyancy or for their never reflecting the coloured rays of solar light. Kratzenstein, who first studied them carefully, estimated the mean diameter of a vesicle to be the $\frac{1}{3600}$ of an inch. De Saussure found the smallest $\frac{1}{4500}$, the largest $\frac{1}{2780}$ of an inch. The investigations of Kæmtz give the $\frac{1}{2400}$ of an inch for their mean diameter. The more recent researches of Dr. Waller (Phil. Trans. 1847) assign to these globules (for he does not call them vesicles) a diameter varying from the $\frac{1}{2500}$ of an inch to three times that size, and he supposes the globules of mist or fog to have ten times that magnitude. His observations are extremely interesting and instructive; yet in reading them it is necessary to bear in mind that aqueous globules formed under the microscope from the breath or warm water may imperfectly represent those produced in the atmosphere by a gradual process, at a low temperature, and under diminished pressure.

Kratzenstein, the author of the vesicular theory, urged that the minute spherical parcels of liquid composing the clouds cannot be globules, since they do not refract and reflect the solar rays. A cloud formed of globules of water is capable of exhibiting a rainbow; but rainbows are seen only when rain is falling and never in the clouds. This argument has been hitherto deemed unanswerable; and in order to elude it, Sir J. Herschel, who could not assent to the vesicular theory, suggested that the globules are incapable of reflecting coloured light owing to their minuteness. On this supposition their thickness cannot exceed the $\frac{1}{40{,}000}$ of an inch, or the hundredth part of the diameter assigned to them by observation. Besides, globules too small to reflect light would transmit it and would not therefore form an opaque cloud. The same philosopher, consistently with his own hypothesis, hesitates to admit the assertion of De Saussure, that "the vesicles (as he called them) may be seen in a good light, even with the naked eye." That globules may be visible to the naked eye, and at the same time buoyant, is believed by the writer of these pages, because he once witnessed the phenomenon when overtaken by a cloud of threatening aspect on Mount Leinster (Ireland), about 2400 feet high. The globules, about half the size of hemp-seed, flitted about in the wind with little inclination to fall.

Aqueous vesicles, being hollow, would be lighter than globules, but still heavier than air, and are therefore not calculated to obviate the difficulty of explaining how the clouds are supported, while they are attended, as Sir J. Herschel has remarked, with the serious difficulty "of conceiving in what possible way they could be formed." Kratzenstein called to the support of his vesicles the viscosity of the air; and this doctrine has been of late years revived. The viscosity of the air, we are told, offers so much resistance to the fall of these minute and perishable particles, that though constantly falling, they can never reach the ground. Mathematicians can deal with the infinitely great and infinitely small, and in so doing wander a good way from reality. The infinitesimal drop of water held immovably in the air bears no resemblance to the dense cloud containing hundreds of tons of water. The proportions of the supported to the supporting body in the two cases are widely different. The air is extremely mobile and kept in constant circulation by partial differences in weight. If by its viscosity it becomes attached to a heavy particle, it of course sinks with it. Viscosity cannot contend with gravitation. It does not prevent the rise of vapour; why should it obstruct its fall? Why are the clouds peremptorily checked by viscosity only at a certain level? They rise and fall to certain heights with changes of temperature. Is this reconcilable with the doctrine of viscosity? Does the same principle which forbids the clouds to fall to the earth by their weight, allow them to promptly obey the impulses arising from the slightest changes of weight? They are sometimes precipitated as rain; is that, too, to be ascribed to the sudden disappearance of viscosity? Cirri at a great height are seen at times to reflect coloured light, whence it is concluded that their vapour is congealed—not, of course, in the form of globules or vesicles, but of minute spicules or needles, such as in the lower atmosphere would assuredly fall to the ground; yet they are thick enough to reflect light, and firmly keep their place at an elevation where the density of the air and therefore its viscosity also are perhaps but a third of what they are near the earth's surface.

The formation of vesicles is inexplicable, while globules of water, light as air and unable to disperse solar light, are no less embarrassing. To meet these difficulties some of the most eminent philosophers and meteorologists have resorted to the expedient of substituting rhetoric for logic, and describe the clouds as phantoms relieved from subjection to the laws of matter by their want of reality. Dove says of it, "a cloud is nothing substantial; it is not a production but a process. It exists only inasmuch as it comes and goes. It has no more solidity than the white foam on a mountain stream." According to Sir J. Herschel, "it is more than probable that when not actually rain-ing, a cloud is always in process of generation from below, and dissolution from above;" and he adds, "in a word, a cloud would seem to be merely the visible form of an aerial space in which certain processes are at the moment *in æquilibrio*, and all the particles in a state of upward movement."

Professor Kloeden, too, describes a cloud as being "rather a continual process than a stable formation; its vesicles falling in fine weather can never reach the ground, being dissipated as soon as they descend into warmer and drier air. But while the vesicles dropping and vanishing are wasted on its under side, fresh ones are supplied above, so that the cloud seems to be immovable." Here we find it assumed that the vesicles fall constantly though invisibly, the cloud being restored from above, while Sir J. Herschel supposes it to be replenished from below and wasted by evaporation above. The last-named eminent philosopher incidentally describes a peculiar cloud maintained and supported, but certainly not by the balanced processes of dissolution and deposition. In calm evenings after sunset, as seen from the Royal Observatory on Greenwich Hill, the vast irregular mass of smoke hovering over London appears to subside. "Its heaped and turbulent outlines become flat, and it sinks rapidly into a low level cloud bank with a very definite outline, and fair sky above. It would seem that each particle of soot, acting as an insulated radiant, collects dew on itself and sinks down rapidly as a heavy body." Here, then, we have the example of a cloud with substance and weight sinking quickly, notwithstanding the viscosity of the air, to a certain level and there supported.

The doctrine that the clouds are unsubstantial, transient apparitions, being advocated by the most eminent men, deserves to be attentively considered. Let us then, in order to examine the grounds of this opinion, observe the formation of clouds. Suppose we have before us a conical mountain 3000 feet high. The hollows on its flanks towards the base are filled on a summer's morning with mist, while a small cloud formed by the ascending vapour hovers above its summit. As the mountain presents more surface than an equal area of level land, and the ascent of its vapour is facilitated by an inclined plane, its active evaporation causes an indraught, and vapour rolls up its sides from all directions. The confluent vapour ascends, till at a certain height above the mountain it is condensed and becomes a visible cloud. This change would never take place if the air were enabled by its temperature to absorb at once the vapour as it arrives; but since it cannot do so, the cloud increases and spreads out till the evaporation from its upper surface equals the afflux from below. Now this equalization does not take place instantly; the cloud may continue to increase for hours, and therefore cannot be wholly without stability.

Again, at the Cape of Good Hope, the south-east wind from the sea strikes on the flanks of the Table Mountain 3582 feet high, flows over it and descends on the opposite side. The vapour with which it is charged becomes condensed in its passage over the summit of the mountain, forming the cloud called "the Table-Cloth;" but as it descends from the height the cloud disappears. These two examples are such as the advocates of the instability of the clouds would select as types of their formation. When told that a cloud is nothing but a process, we are given to understand that the condensation and dissolution of visible vapour go on together *pari passu*. But the fact is, that these antagonistic processes meet in perfect equality only in particular cases; their great inequality is the general rule.

On a fine morning in spring or summer, the ascending mist often cuts off the view of the heavens. As it rises, however, the sun pierces through it, and the opening screen shows glimpses of the blue sky; till at length the masses of mist continually rising higher, take the form of clouds. They are now cumuli, wide apart, with firmly defined outlines, unlike the more transient cloud just described as formed above the mountain, the irregular edges and prostrated figure of which betrayed its struggle for existence. No one who has ever attentively observed the formation of these cumuli can doubt that they are formed by a visible process in which dissolution has no share, and that so long as they remain visible, they are composed of the very vapour which he saw rising as mist.

The afternoon may present a very different but equally instructive spectacle. After some hours of great heat and not a speck in the sky, about 2 o'clock some haze is observable, and in less than half an hour the whole heaven is closely covered with dark clouds, which have manifestly descended from the upper regions of the atmosphere. This is a phenomenon of almost daily occurrence in intertropical countries. But how can this sudden accumulation of cloud take place unless the process of dissolution be absent? and if it be absent, then the cloud has some stability. Again, the mottled, the mackerel cloud, and the cirri affect peculiar figures. Indeed some tendency towards regular arrangement may be seen in clouds of all kinds in calm weather. This might be explained by attractions and other inherent properties of matter. But how could it be accounted for in an unsubstantial process, at once in a state of creation and extinction?

But the strongest argument against the apparition-theory of clouds is, that it cannot be reconciled with the most important doctrines of terrestrial physics inculcated by its eminent authors themselves. They tell us that by means of winds and clouds, abundant rains are distributed over the globe, and carried from the equatorial ocean to lands in high latitudes. But how can that which is unsubstantial and of momentery existence bear such carriage? If clouds be only processes of simultaneous growth and extinction, then every cloud must have originated in the spot where it is seen. It cannot in that case be true that the warm and abundant rains that fall on the Alps, on the coasts of Ireland and of Norway, have come from the middle of the Atlantic Ocean. Yet it is certain that rain is carried by clouds to a great distance. When Dr. Barth was travelling southwards across the Sahra to Bornu, he encamped in a dry valley in lat. 22° N. But suddenly rain fell, and the dry valley became the bed of an immense torrent. That rain certainly never originated in the evaporation of the desert. Droughts of three or four years continuance occur at times in South Africa. But though in such cases rain fails, the clouds do not fail. Heavy clouds seeming to threaten a deluge roll over the Winterberg (in the Cape Colony) for month after month, and reach the sea apparently undiminished, after passing over many hundred miles of arid, sun-burnt country, incapable of contributing any vapour to their support. Clouds, and the dust conveyed by them, may naturally be supposed to come from the same quarter. Now the sediment left by heavy rain that fell in a storm at Grenoble in 1855, when examined with the microscope, was found to contain organisms peculiar to the coast of South America.

The vesicular theory of the clouds must be rejected, because while it fails to account satisfactorily for their buoyancy, it leaves wholly unexplained the formation of vesicles, which seem to owe their existence not to any natural law, but to the exigency of a theory. They cannot receive any support from viscosity; for particles of water, however small they may be, must have weight, which is added to the weight of the air that entangles and retains them; and air and water together must yield to gravitation. Viscosity may hold but cannot support. The viscosity of air does not impair the mobility of air; how, then, can it affect the mobility of any thing else? In a cloud half a mile thick, therefore, the whole weight of the watery contents, say 1000 tons, would in this way rest on its lowest plane. If the specific gravity of the vesicles exceed that of the air, the diminution of their size cannot affect the ultimate result; their weight must be borne by the base of the cloud. But the atmosphere beneath a cloud gives no sign of superadded weight, and therefore it cannot be admitted that it offers any resistance to the fall of the fluid. There is no compression in a cloud, the density of which at every altitude is that of the air around it. A cloud does not float as a coherent mass, sinking in the air at its centre, and with a convex surface downwards, but is perfectly level at the base; and yet above it is piled up in irregular masses, which, looked down upon from a balloon, resemble snowy alpine scenery. It is manifest, therefore, that the upper parts of the cloud do not exercise the least pressure on those below them. In short a satisfactory account of the constitution of clouds must explain the fact that every globule in them is buoyed up, so as to be as light, while it moves as freely, as air. It needs no viscosity to support it, and knows nothing of pressure or resistance.

But if the aqueous particles of clouds are not vesicles, they must be globules, which are still heavier; and it is incumbent on us to show how globules may be supported in the atmosphere by means less inexplicable than the formation of vesicles, and also to account for their inability to disperse heterogeneous light. That mists ascend and clouds float in the air are plain facts. As mists rise with the increase of heat in the morning, it may be inferred that they are aided by an ascending current of air. But this is not enough. It suggests, however, that the watery particles must be extremely minute; for the weight of an aqueous globule is proportional to its volume, the external sustaining forces to its surface. But the volume increases as the cube of the diameter; the surface only as the square. Consequently as the globule increases in size, its surface decreases in relation to its weight, and its buoyancy diminishes. If, therefore, the aqueous particles of mist were to strike together and coalesce as they ascend, they would inevitably grow too heavy and fall at once to the ground; and this would assuredly take place if they were not by their nature incapable of such collision; for they carry off with them the resinous or negative electricity of the earth's surface, and consequently repel each other. This electricity invests each globule with a small atmosphere of repulsion, which, acting on the air, has the effect of making the globule virtually occupy a space much exceeding its actual volume, and thus renders it buoyant.

The mist which has risen in the manner just described may, under certain circumstances, become a cloud; but it will be more to our purpose to follow it through the ordinary course of evaporation. The minute globules of the mist, with little mass and much surface, and under reduced pressure at a great elevation, easily yield to the heat of the sun, and go off in the gaseous form. The low temperature of the air above the clouds is due in a great measure to its diathermancy. It allows the heat of the solar rays to pass through it undiminished; but not so the aqueous particles; they seize and absorb the heat with avidity and expand into transparent vapour. In this condition they rise to the altitude at which positive electricity is predominant. And now another change awaits them. As the sun sinks to the horizon, the temperature of the atmosphere falls, and the vapour diffused through an attenuated medium condenses into extremely minute globules, well charged with positive electricity. Now become opaque, it descends to a lower level of denser air, where the electricity enwrapping the humid molecule suffices to support it. Descending clouds of this kind seem to be generally lighter and to rest at a higher level than clouds that rise from the ground. Should the electricity of the cloud be withdrawn, as in thunderstorms, the globules left at liberty to coalesce fall to the ground as rain.

For the admissibility of these views, appeal may be made to the recorded opinions of Sir John Herschel. Speaking of the connexion of electricity with gaseous matter, that philosopher says, "the simplest conception we can form is that of its investing the ultimate molecules of vapour as an electric coating." Again, he observes, "the comparatively high electric state of fog (and cloud is nothing else) is an obvious consequence of this. Every minute globule of water of which fog consists carries about with it an electric coating, which it is ready to part with by contact discharge to the surface of any conductor ; and the denser the fog and the larger the globules, the greater the amount of electricity given out." In writing those words he had in view only the development of atmospheric electricity, and took no heed of some particulars of great importance in another line of speculation. The larger the globule, the greater indeed will be its electricity ; but though absolutely greater, yet proportionally less. As the globule increases in size, its connexion with the electricity that supports it becomes more unstable ; the latter is more likely to be discharged, the former to fall as rain. A coating of electricity implies a coating of repulsion. Globules thus invested repel each other and also dry air. Thus electricity, itself imponderable, creates a vacuum around them. If a molecule of water be enwrapped with electricity of its own breadth, the resulting globule will have 3 times the diameter, 9 times the surface, and 27 times the volume of the molecule without any increase of weight. If we suppose the energy of the electricity to extend to 5 times the breadth of the molecule, then the increased diameter, surface, and volume of the latter will be respectively as 11, 121, and 1331.

Thus it appears that a minute globule of water is supported in the air, just as a fine cambric needle floats on water. Between clean polished steel and water there exists repulsion. Some force is required to bring them into contact. If, then, a small clean needle be let fall horizontally and from a short distance on water, the latter will yield to the repulsion, and will receive the needle, without contact, in a concave bed, the width of which will be to the opposed semicircumference of the needle in the inverse proportion of the specific gravity of water to that of steel. If the latter be 7 times that of water, then the breadth of the concave bed of water supporting the needle will be sevenfold the repelling surface of the latter. But the repulsion that takes place between water and steel has not the energy of electricity, nor can it operate at so great a distance. A small globule of water may possibly occupy, by means of its electric repulsion, a space equal to a thousand times its own volume. The vigorous repulsion exercised by electricity is shown by the speed with which the smallest charge of it disperses light powders. Acting thus on the air, it protects the enclosed vapour from contact, and thus may account for its persistence in low temperatures.

But the sun shines on these globules in the clouds; and if they refract the solar rays, why do they not reflect the coloured light produced by such refraction? We answer, it is not certain that they refract the solar rays. The ray that falls on a raindrop converges to its back, and thence reflected, is refracted and appears as coloured light. But a ray falling on the vacuous envelope of a minute globule diverges from the latter, and cannot therefore be reflected from it. Clouds and mist are brilliantly white when the sun shines on them. They admit the light, entangle and retain it. In this respect they resemble froth and foam, which are opaque mixtures of air and water or other transparent fluid. But these differ from the former in being vesicular; and it is worthy of remark that the vesicles composing froth all cohere, and completely imprison the air; whereas in clouds and mist the fluid particles move freely, repelling each other. On a dry summer's day the atmosphere often appears misty; when it afterwards becomes perfectly transparent, rain is predicted. That opacity may be attributed to the discontinuity of the molecules caused by electricity. The mists called by the Spaniards Calína and the Qobar of Abessinia, described by M. d'Abbadie, are probably of the same nature, differing only in degree. In order to be perfectly transparent, a medium must be continuous and homogeneous. The supposition that the molecules of vapour are coated with electric repulsion may serve to account for their conservation of the gaseous form in very low temperatures, since they are thus kept from actual contact with the dry air. Increase of heat is followed by still greater increase of vapour, if water be present, but it weakens electricity. Hence high temperature leads to rain. The support of the clouds depends on the ratio subsisting between the quantity of the vapour and the strength of the electricity.

If one small slip of plate glass be laid on another, the transparency of the couple is evidently less than that of the single slip. But they do not touch: this is easily demonstrable; for by pressure they may be forced into contact at some point, round which will be seen the Newtonian coloured rings. At this point their transparency is restored, decreasing with distance from it. At the same point there are no reflections from the surfaces in contact; they, in fact, there cease to be separate surfaces: but elsewhere may be seen three reflected images (of a pin's point, for example), the middle one being the more strongly marked; for on close examination it will be found to be formed by the two images, nearly coinciding, reflected from the surfaces that lie together. The perception of the duplicity of the middle image, be it remarked, is equivalent to perceiving the distance between the two slips of glass. Now if the experiment be made, not with two slips of glass, but with a pile of a score laid together, they will doubtless be found opaque, though transparent if forced into contact. If instead of slips of plate glass we could employ minute glass globules, they would certainly, exposing a greater extent of surface, hold together far more electricity. They would undoubtedly form an opaque mass; and if very small in relation to their electric coating, they would not reflect coloured light. This illustration of the nature of a cloud is the more apposite, since there can be little doubt that the repulsion existing between two surfaces of glass is due to the electricity adhering to them.

An eminent meteorologist informs us that vesicles and ice-crystals, though heavier than air, are nevertheless supported by its resistance to their downward pressure. Is not this contrary to the laws of nature and to daily experience? Is any thing visible and heavier than air ever supported by calm air near the ground? The vesicles, he observes, present much surface; but surely the frozen spicules present very little surface, and must be upheld by something else than the resistance of viscosity in a rarefied atmosphere. The fact that clouds lie in strata at different heights favours the supposition that they are supported by adventitious aid; for it is easier to believe in different degrees of electrical development than in many forms of humidity differing in specific gravity.

CHAPTER XVI.

Rain.—Causes of Precipitation.—Cold, Pressure, Mixture.—Rate of Rainfall—how measured.—Growth of Rain-drops.—Unequal Distribution.—Sudden Rains.—Constant Rains.—Region of two Rainy Seasons.—Winter Rains.—Summer Rains.—Rains at all Seasons.—Rains of Eastern Africa.—Rainless Tracts.—Rains of Europe—of the United States.

The clouds consist of aqueous vapour rolled up to be transported by the winds. Being for the most part offspring of the ocean, their birth would be fruitless, and the purposes of circulation would be frustrated, were they to end where they began ; but borne off by the winds and enabled to precipitate their contents on the land, they unceasingly diffuse over the earth the humidity required for life and organization. The mode of its distribution in respect of season and quantity now remains to be considered.

Precipitation of rain takes place as soon as the atmosphere is surcharged with vapour, or when the limits of its saturation are exceeded. Wherever water is present and the temperature high, the air is sure to be loaded with vapour, the least increase of which would cause repletion. Evaporation is then repressed, but is ever ready to go forward. In this state of things any compression, such as would be caused by a discharge of electricity or a fall of temperature, suffices to condense the vapour, which falls as rain, and, under the circumstances described, is immediately replaced by fresh vapour to be precipitated in its turn. But by this fall of rain the cloud- or vapour-bearing volume of atmosphere is not completely drained. No longer fully saturated, it holds the moisture that remains to it with firmer grasp. If it be carried off by the wind to a cooler latitude, the limit of saturation sinks with the temperature ; the same cloud-current, therefore, again throws down rain, and repeatedly goes through the same process until completely exhausted. All the humidity that floats in the atmosphere may be wrung from it by cold. But even without any considerable fall of temperature, the mixture of two currents of air with different temperatures always lowers the point of saturation, and therefore tends to cause a fall of rain. It hardly needs to be expressly pointed out, that if we be justified in supposing the buoyancy of cloud-vapour to be due to the electricity that envelopes its particles, then any thing that withdraws or extinguishes that electricity (as, for example, contact with or close approach to land) must bring on precipitation.

An atmosphere completely saturated, and in which precipitation is always imminent, occurs often between the tropics, and always in the central region or belt of equatorial calms. There the cloudy canopy overhead appears ever ready to fall under the load of the humidity it sustains. The damp, warm, drowsy atmosphere and the sea beneath it are languid and motionless. On a sudden comes a thunderstorm, then whirlwind, and the rain falls in torrents such as are rarely witnessed elsewhere. The tornado over, another interval of sultry torpor succeeds.

The rate at which rain falls may be easily and accurately measured by receiving it perpendicularly in a vessel with parallel sides. The surface on which it is then collected and measured being equal to that on which it falls, it is evident that the height of the water collected at any time is proportional to the quantity that has fallen. But the height of the water collected from rain in this manner increases very slowly; in general it amounts only to a small fraction of an inch per day. It is therefore found more convenient to contract the vessel that finally receives the rain, the variations in the quantity of which are thus visibly magnified and more easily observed. Let us suppose, then, a funnel-shaped vessel of metal, opening above with an area of 100 square inches, and communicating below with a glass tube having an area equal to 1 square inch. It is obvious that water falling on and covering to the depth of 1 inch the area of the funnel would fill 100 inches of the tube, that one tenth of an inch on the former would make 10 inches in the latter, and that a fall of a hundredth of an inch of rain on the funnel would be an inch, easily and exactly measured in the tube. To make the indications of the rain-gauge perfectly correct, care must be taken that the rain fall perpendicularly on the aperture made to receive it; for if it falls obliquely the breadth of the column of rain received will be really less than that of the funnel. It ought to be contrived, therefore, that the wind, as it drives the rain, may at the same time change in a suitable manner the position of the rain-gauge.

This instrument enables us to ascertain that rain-drops increase during their fall from above. If rain-gauges be placed on the summit, at the middle, and at the base of a high tower, that at the top will be found to collect the least, and that on the ground the greatest quantity of water. Thus the tower of York Minster is 212 feet above the ground; the roof of the adjoining Museum has a height of 43 feet; and observations continued for four years (1832 to 1835 inclusive) show that the quantities of rain that fall on the tower, the roof of the Museum, and the ground respectively are in the ratio of 59, 79, and 100. Observations made at the Observatory in Paris and at Besançon give similar results. From experiments made in York in 1840 to determine the growth of the rain-drop within narrower limits, it was found that its increase may be represented by the following numbers:—

12 feet above the ground	8206 or 0·976
6 ”	8259 or 0·982
3 ”	3814 or 0·989
0 ”	8407 or 1·000

More recent experiments concur in proving the increase of the falling rain-drop, and that it increases most rapidly near the ground; but as to the rate of that increase, they differ so much as to justify the suspicion that it is not constant, but depends on the state of the atmosphere.

It appears certain, however, that the rain-drop ordinarily gathers humidity as it falls; and since its increase far exceeds what could be explained by supposing that it condenses all the vapour met with in its passage through the air, we must conclude that minute particles of water, or what may be described as aqueous dust, float in the atmosphere when it is in a rainy condition. Hence showers of rain, in this case called by the French *serein*, often fall from a cloudless sky. Vapour being decidedly lighter than air must tend to ascend; but liquid particles assuredly sink, however slowly; and when the barometer falls, they, becoming relatively heavier, sink more rapidly. Hence it is that on the approach of rain aluminous flags become wet, and drops of water may be seen on oil-painted walls.

At the equator, where the atmosphere is loaded with moisture and the piles of clouds rise to an enormous height, the fall of rain must be incomparably greater than elsewhere. But there are also extensive tracts of the earth on which rain seldom or never falls. Where it is not wholly wanting, the quantity that annually falls varies from 3 to 600 inches in the year, though the last amount (50 feet) falling at Cherraponjee in the Khasya hills, at the head of the Bay of Bengal, may perhaps be regarded as exceptionally great and elsewhere unapproached. When it is considered that an inch of rain on an acre gives above 101 tons of water, it will be understood what floods must be produced by an annual fall of 50 feet of rain or of 60,600 tons per acre. The annual rainfall about London does not exceed 25 inches. Those who in temperate climates may think that they have experienced heavy rain would be astonished at the sudden deluges that sometimes take place within the tropics. In the belt of equatorial calms the boats hanging at a ship's side are often in a short time filled with water, and the surface of the sea becomes perfectly fresh. Dampier relates that when lying at anchor at the Isle of Gorgoña (lat. 3° N.), on the coast of New Granada, he and his crew drank chocolate on deck while it rained heavily; but they were unable to empty the calabashes, the rain filling them as fast as the men could drink. On land these prodigious torrents are even more startling than at sea.

Sudden and heavy falls of rain sometimes take place beyond the tropics. In October 1822, 30 inches (French) of rain fell in Genoa in one day, and the like occurred at Gibraltar in November 1826. Joyeuse, in the valley of the Rhone, experienced in October 1827 a fall of rain of nearly equal measure. In England, the heaviest rain recorded in the lake-district of Cumberland amounts to 6·62 inches in one day. At Portree, in Skye, in 1863, 12½ inches fell in 13 hours. Even the dry steppes of Southern Russia are not totally exempt from occasional falls of heavy rain; and in the Government of Samara there once fell in one day (2nd August, 1853) 3·70 inches. The greatest rainfall recorded in the United States is 18 inches at Catskil, on the 26th July, 1819. In Cherraponjee, just outside of the tropic (in lat. 25° 17′ N.), there fell in one month (June 1851) 147·2 inches, or more than falls in England in four years.

In the equatorial belt of calms rain falls at all seasons, and most heavily about the time of the equinoxes, when the sun crosses the equator. Heavy rainfalls, half a year apart, beginning in March and September, characterize the climate of all places near the equinoctial line. But the luminary on its way back and forward from tropic to tropic passes twice in the year over every intermediate point, and everywhere as it approaches the zenith rain begins to fall. The points met with in succession as the sun recedes from the equator, occur in reversed order on its return. Therefore places distant from that line have in the northern hemisphere their early rains later than the vernal equinox, and in the same degree their late rains earlier than the autumnal equinox. They have two rainy seasons, separated by a less interval in their summer half year, and a longer interval including winter, the inequality of these intervals increasing with the distance from the equator. But as at the tropic the two rainy seasons come nearer together, they unite and form in June and July one rainy season of greater continuance. Thus the intertropical region may be distinguished with respect to rains into five zones, viz. :—1st, that of the calms, with almost daily rain all the year round, and heaviest at the equinoxes (this extends from lat. 3° S. to lat. 5° N.) ; 2ndly, two zones (N. and S.) of the double or intermitted rains, extending beyond the former to lat. 15° in both hemispheres ; and 3rdly, the two zones of single tropical rains, terminating at the 25th or 27th parallel N. and S. Near the tropics the rainy season is followed by ten months of dry weather, between that and the equator, where rain is incessant, may be found every intermediate gradation in the distribution of rain.

Though there is much truth in the seaman's rule, that (between the tropics) rain follows the sun, yet in some cases its distribution seems to depend less on the movements of the luminary than on that of the belt of equatorial calms, which, confined within narrower limits, is also less regular. That cloud-region is the magazine of tropical rains, and whenever its excursions to the north or south fall short of their usual extent, complaints may be heard, even within the tropics, of late or insufficient rain. Local circumstances also, as sea-winds or the vicinity of mountains, may interfere with the course of tropical rains, as above explained. Near the equator rain appears to be everywhere nearly constant in quantity. At some distance from the equatorial belt of calms, under the trade-winds, little rain falls at sea. It might be supposed that the early and late rains within the tropics would always be equal. But on land, at some distance from the equator, and especially at great elevations, where extremes of temperature are often felt, the accumulation of heat depends on the prolonged continuance of the sun's presence; and consequently, since the greatest heat follows midsummer, and humidity goes with heat, the autumnal or late rains are generally heavy, while the early rains are so light as almost to escape notice. Thus in Abessinia rain falls early in March, yet it is often stated that the rainy season of that country is from June to September.

It is a general character of tropical rains that they fall only by day. The nocturnal sky in low latitudes is ordinarily clear, the forenoon bright and cloudless; but soon after midday clouds begin to gather, and at the hour when the diurnal heat has reached its maximum (between two and three o'clock) and begins to decline, or, as some suppose, when the ascending current of air ceases, down comes a flood of rain, which rarely lasts till sunset. In some places, as Rio de Janeiro, the cessation of the storm is as regularly timed as its commencement. Though rain and thunderstorms at night are generally unknown in tropical countries, yet they do sometimes occur in peculiar situations among or near mountains. On the Abessinian highland the time for rain and thunder is from two o'clock in the afternoon to sunset; while in the adjacent country of Sennar, the comparatively low tract further north-west, they occur only at night. Dampier was of opinion that more rain falls by night than by day; but on this point, as far as low latitudes are concerned, he is at variance with all modern authorities.

Since the tropical rains owe their copiousness to the evaporation of the ocean, collected and transported by the trade-winds, it is obvious that less advantage will be derived from them by countries situate far from the ocean, or to the leeward of the trade-winds, or in any manner debarred of their influence. Intertropical America lies on the windward side of the Atlantic Ocean, and receives the full benefit of its most humid winds. Hence the tropical regions of that continent are, with little exception, one immense and most luxuriant forest, extending from the shore of the Atlantic Ocean on the east, to far up the sides of the Andes. But these mountains, rising above the ordinary level of the rain-clouds, forbid their further progress; and Peru, on the western side of the Andes, has no rain; it is cut off from the winds of the Atlantic, and is to windward of those of the Pacific. Within the belt of calms, a little further north, the intervention of the winds is no longer needed, and Guayaquil, on the shore of the Pacific, has frequent and heavy rains.

The vapours of the Pacific Ocean, carried westward by the trade-winds, are distributed over the Malayan archipelago and Southern Asia by the monsoons. Some places, however, such as Singapore, situate close to the equator (lat. 1° 17′ N.) and within the belt of calms, have constant rain independent of the wind. In the precipitation of rain the monsoons follow the same rules as the trade-winds. At a little distance from the equator there are two rainy seasons, answering to the passages of the sun across the zenith, and uniting nearer the tropic in a single season of summer rains. On the coast of Travancore (lat. 9°) these rains begin with the monsoons in April or May; in Bombay (lat. 18° 53′) a full month later, or in the beginning of June. In the latter place they do not attain their maximum till July, nor in Calcutta (lat. 22° 33′) till August. When checked and forced to accumulate by mountain-barriers, these winds, fresh from the equatorial ocean, precipitate immense floods. While Singapore, nearly under the equator, has annually but 90 inches of rain, Uttra-Mullay and Mahabuleshwur, on the west side of the Ghâts (coast of Malabar), have respectively rainfalls of 262 and 254 inches. Cherraponjee, on the Khasya hills, at the head of the Bay of Bengal and backed by the Himâlaya, has no less than 610 inches (50 feet 10 inches).

Within the region of the monsoons there is no complaint of insufficient rain. But the course of the trade-winds is there effectually stopped; and consequently Africa, though lying within the geographical limits of greatest moisture, is, through want of tropical oceanic winds, collectively a dry continent. The periodical S.E. wind which visits the eastern coast bears nothing like the mass of vapour accumulated over the Atlantic Ocean by winds from both sides. South-east winds at a great height, far above the monsoons, carry rains to Abessinia, a country which, though great rivers descend from it, has yet a decidedly dry climate. The equatorial portion of the African continent seems indeed to be well watered: so much may be concluded from the narratives of Captains Burton and Speke. But it must be remembered that these officers, in penetrating to the interior of the continent, performed a great feat with very little scientific preparation. Captain Speke dwells much on the constant rains and luxuriance of Uganda; but he seems never to have reflected that on the borders of a great lake, or inland sea, and under a burning sun, he may have experienced a merely local climate. Central Africa seems to owe its abundant rain to its numerous large lakes. While the S.E. wind brings some humidity to Africa, the N.E. from Siberia, and more persistent, brings dryness. Hence the aridity of the Libyan deserts; hence it is that the tropical rains in Northern Africa do not go north of the 17th parallel. Drought and barrenness begin to appear even at the 15th parallel on both sides of the equator. At Gondócoro, on the White Nile (lat. 4° 54′), and in Ukamba (lat. 2° S.) the profession of rain-maker is held in high consideration.

The rains described above are those which, following the sun, characterize an atmosphere laden to repletion with aqueous vapour, most heavily laden at the hottest season, and which, on contact with land, is ready to part at once with its burden. But such repletion is not universal. The vapour-bearing current from the equator, on its way to high latitudes, sinks as it proceeds with some loss perhaps of temperature. The line from which it arises moves a few degrees N. and S. in the course of the year. When, therefore, it first comes to the ground as the up trade or equatorial S.W. wind, at its southern limit, in the winter of the northern hemisphere, it waters a tract distinguished by having only winter rains. These subtropical or winter rains fall on the northern shores of Africa, from Morocco to Cairo, at Bagdad, Candahar, &c., or collectively between lats. 30° and 36° N.

But immediately adjoining this zone of tropical rains, and in the northern hemisphere a little south of it, lies another zone, which, deprived of its vapour by the trade-winds, also lies beyond the reach of the tropical rains; it is therefore rainless and consigned to sterility. This zone is plainly marked across the old world, where a combination of circumstances, in Asia especially, gives it additional breadth, by the great African desert, or Sahra, Arabia, the Syrian desert, Southern Persia, Turkestan (which is rainless though fertilized by irrigation), the desert of Gobi, and the Mongolian desert north of China (see Plate 7). The peculiarities of the Asiatic continent carry it northwards. In North America it reappears in California and the interior of Texas. In the southern hemisphere the dry zone in Africa lies on both banks, but chiefly the northern, of the river Orange, though towards the sources of that river, and within the reach of the S.E. winds from the sea-coast, aridity ceases, and the aspect of the country changes. South America exhibits it in the Pampas of Buenos Ayres, and still more plainly in the desert of Atacama, on the western coast. Finally, the dry zone exists in Australia with unusual extension.

As the sun advances in northern declination, the equatorial S.W. wind in the northern hemisphere also goes on to its northern limits, whence it again retires, thus passing twice in the year with its load of vapour over the space measured by its oscillation. Consequently the countries situate in this interval have annually two periods of comparatively heavy rainfall, more or less widely separate and nearer to winter or to summer as the situation is further to the south or north. In Algarve (Portugal) the winter rain is most abundant: rain falls at the equinoxes, but hardly any in summer. In Gibraltar, Lisbon, and Mafra, 50 per cent. of all the rain falls in winter, the rest in spring and autumn. Coimbra, owing to its position at the foot of the Sierra d'Estrella, is notorious for the quantity of rain (115 inches) that falls there, chiefly in October and November. In Madrid there is heavy rain from March to June, and again from August to November. In Italy generally there is little rain between April and October, though on the eastern side of the Apennines, at Verona, Padua, and Venice, the early rains fall in May and June. But the further north we go in the Peninsula the more equable is the distribution of the rain throughout the year. At Palermo the spring maximum of rain falls in March, at Naples and Rome in April, at Milan in May, and at Udine in June; while the autumnal maximum, which at Naples and Rome falls in November, occurs at least a month earlier at places north of the Po.

On the coasts of Greece generally the year is divided into a dry and a wet season, the former extending from April to September. It often occurs on the shores of the Mediterranean, at Corfu, Athens, Crete, and Malta, &c., that for two or three months in summer not a drop of rain falls. But further north the system changes; rain falls at all seasons, and though still inclining to fall heavier in certain months, it ceases to be strictly attached to any. In the valley of the Rhone the spring maximum of rain occurs in May, in that of the Saone in June; but in Paris the maximum of the year falls in June or July; and central Germany is still more decidedly watered by summer rains. The line that separates the subtropical or winter rains from the northern summer rains seems, in the neighbourhood of the Alps, to lie somewhere about the 46th parallel of latitude. But let it be observed that these summer rains fall in countries which have rain in every month of the year; and as the summer rains, though comparatively heavy, are accompanied by increased heat and evaporation, they never convert the summer into a wet season.

In Great Britain the chief rainfall takes place in autumn; and this is most evident at its western sides. Ireland, with a climate still more oceanic, has its heaviest rains in January. In both islands the quantity of rain decreases from west to east, as, indeed, it does generally in the temperate latitudes of Europe, if local irregularities be disregarded. The mountains in both being chiefly on the western side receive the rain on their windward slopes, while the country to leeward of them remains comparatively dry. Cahirciveen, facing the Atlantic Ocean, near the S.W. extremity of Ireland, has annually 59·4 inches of rain, while Portarlington, in the middle of the island, and sheltered by mountains to the S.W., has but 21 inches. But this instance of unequal rainfall is far exceeded in England. The mountains of Cumberland present to the prevalent winds funnel-shaped valleys which collect the vapour, and they are at the same time high enough to intercept the clouds in autumn and winter. Hence proceed local rainfalls elsewhere unequalled in Europe; while at Whitehaven the annual fall of rain is 44 inches, at Keswick 60, Seathwaite (at an elevation of 368 feet) has 142 inches, and the Stye (948 feet high) 189 inches. Bristol, at some distance from the sea and in an open country, has but 23 inches of rain; Glasgow, similarly situate, only 21. On the eastern coast, at the same time, the annual rainfall at Hull and Edinburgh is reduced to 18; at London to 25 inches.

Belgium and Holland, near the sea, resemble England in having most rain in autumn; but further in they conform to the system of middle and eastern Europe, rain falling at all seasons, but with a maximum in summer. Throughout the continent of Europe rain diminishes in quantity from S.W. to N.E., not, however, with perfect regularity; for wherever mountains cross that direction, a local increase by accumulation takes place, at the expense of the country lying further eastward. Thus, on the southern borders of Bohemia, Stübenbach has an annual rainfall of 81 inches, chiefly in winter; while at Prague, in the central hollow of that country, the rain is reduced to 14 inches. Near the Riesengebirg again, on the western side, the rainfall rises to 43 inches, and then again in Silesia sinks very low. On the Hartz mountain there is a fall of 50 inches; and consequently Mecklenburg, beyond it to the N.E., is a dry country. From the middle of Germany eastwards there is a deficiency of moisture in spring. In Scandinavia the copious rains of Norway, where lofty mountains facing the sea intercept the vapour-bearing currents from the S.W., account for the drought of Sweden. Further west the Uralian mountains again extract moisture from these currents, which are thus exhausted when they reach Siberia. As the mountains of Norway, so the lofty ridge of Caucasus, where it approaches the Black Sea in Mingrelia, causes an extraordinary fall of rain, which at Redout Kalé amounts to 63 inches; while Baku, east of Caucasus on the western shore of the Caspian Sea, has but 13. This scanty supply it owes to the N.E. wind, which, crossing the Caspian Sea, bears with it some humidity. The S.W. wind is here frequent; but blowing from Africa, it is quite dry; and it deserves to be remarked that the whole tract of country lying northeastward from Africa bears marks of desiccation still in progress.

The trade-winds do not penetrate into the West-Indian seas or beyond the peninsula of Florida. They are imperfectly developed on the western side of the northern Atlantic, and where the primary wind fails that derived from it must be also wanting. Hence there is no equatorial wind from the ocean carrying rain to the eastern portion of the North-American continent: the S.W. winds of the Pacific shower their contents profusely on the N.W. coasts of America; but there the lofty barrier of the Rocky Mountains forbids their further progress eastward; the coast ranges of California even prevent them in a great measure from reaching the loftier mountains further east. To the continent east of the Rocky Mountains, therefore, those winds convey no moisture. While Sitka, in lat. 57° 3′ N., on the north-western coast has an annual rainfall of 88 inches, a great tract of country on the eastern slope of the Rocky Mountains is a dry desert. The United States derive their chief supply of rain from the Gulf of Mexico. The humid sea-wind from the south passing up the valley of the Mississippi and deflected to the right is the rain-bearing S.W. wind of the populous country on the shores of the Atlantic. As it proceeds on its course its stores diminish, and the quantity of rain decreases towards the north. In winter the moist current from the south meets the intensely cold current from the north, and the increased condensing-power makes up for the reduced supply. Sea-winds also carry frequent showers from the warm current of the Gulf-stream; so that in the United States rain is very equally distributed in all seasons throughout the year; yet going northward from the Gulf of Mexico it is found that the rain that falls in winter decreases, while that of summer augments, though not in the same proportion. Mobile, in lat. 30° 13′ N., has a rainfall of 65 inches; Fort Snelling, in lat. 4° 53′, 25 inches. It must not be supposed that the N.W. wind of the interior of the United States has any connexion with that of the north-western coast of America, which is the S.W. wind of the ocean deflected by the mountains. These two winds have totally different characters: the latter, warm and humid, gives the verdure of a southern climate to lat. 60° on the coast; the former, dry and cold, carries in the interior the climate of the pole to lat. 40°.

The distribution of rain and its connexion with the wind-system may be rendered clearer by a brief recapitulation accompanied by a diagram (Plate 7). The down trade-winds blowing from temperate to torrid latitudes, and deflected till they become east winds, collect a vapour-laden atmosphere in the belt of calms, near the equator. In this belt rain falls continually, of which Singapore may serve as a type, independent of the winds. Beyond the belt of calms the distribution of rain within the tropical region depends more on the wind, which, carrying it westward, throws it on the eastern coasts of continents, over their plains, and on the eastern sides of high mountains, leaving their western sides unwatered. This is plainly exhibited in South America, Brazil being collectively a vast luxuriant forest, while Peru, on the western side of the Andes, is a rainless and comparatively naked land. In tropical Asia the system of the winds, and consequently that of the rains also, is disturbed. Where the south-west monsoon prevails the western shores are better watered than the eastern. Thus the rainfall at Bombay exceeds that at Madras. Remarkable accumulations take place wherever the current, unexhausted and on its first meeting with land, strikes against mountains, as on the coast of Malabar. The influence of local circumstances may be estimated by comparing the rainfall on the Ghâts with that on Cape Comorin. By the stoppage of the trade-winds in the Indian seas Africa loses its full share of the tropical rains. On its eastern side, north of the equator, the low land of Africa has but little rain.

Rain is very unequally distributed over the globe. Its abundance at any place depends on temperature, position in respect of the humid winds, proximity to the ocean, altitude, and other circumstances which may be collected from the preceding pages. Even in districts of moderate extent, and enjoying everywhere the same general conditions of climate, the fall of rain is rarely uniform throughout. It would appear that the ascending current of dry, heated air collected from the chimneys of a great city may diminish its rainfall; for less rain falls in London than at Chiswick, Tottenham, Kew, or Greenwich. In every country may be found spots that seem to attract rain. Vapour-laden winds from the sea pour their moisture copiously on the first land that meets them, generally on condition that the land is cooler than the sea. Mountains high enough to bar the advance of the winds may rob them completely of their vapour; but mountains are not necessary for the attraction of rain. The south coasts of England have at least 30 per cent. more of rain than the country ten miles further in. The chief fall of rain on mountains generally takes place on the side that faces the wind; but in many cases the great floods are poured down in the rear of the mountain after the clouds have passed over it. This may perhaps be ascribed to the circumstance that the cloud-bearing current of air cooled in its passage over the mountain, descends to mix with a warmer current which has made its way through the valleys; but united, the two currents of different temperatures are unable to retain the amount of moisture which they separately held. This mixture of currents is probably the most frequent cause of local wetness of climate, which may therefore be expected to occur most frequently among hills and at the openings of valleys. It is said that the clouds driven by the south-west wind that pass over Kent without dissolution, often, as soon as they have crossed the Thames, pour down their contents on Essex. Doubtless over and to leeward of the river they enter a more humid atmosphere, which decides their precipitation.

It is extremely difficult to form any estimate of the quantity of rain that falls on the earth's surface. We know the rainfalls at various points; but while ignorant of the area to which each statement applies, we cannot assign to it its proper value in the calculation. Exceptional phenomena being remarkable are most observed; but no general conclusions can be drawn from them. Thus we learn that Seathwaite in Cumberland has annual rain to the amount of 142 inches, while the hill called the Stye, 948 feet high, not quite two miles from the preceding, has 189 inches. In fact 183 inches has fallen in a year at the former place, 224 at the latter. No other instance is known of such excessive rainfall in the temperate zone. On the other hand, the rainfall at Hull, on the eastern side of the kingdom, is only 18 inches. How can we expect to discover by means of data of this kind the mean rainfall of England? The great danger of being misled by excessive rainfall on a small area in the west may be judged from the fact that the mean rainfall of the kingdom is assumed by the best authorities to be only 34 or 35 inches.

But if, beginning with the torrid zone, we endeavour to summarize results, we find that Dacca, the district of India which includes the Khasya hills and Cherraponjee, may have an annual rainfall of 229 inches, while that of the western Ghâts will be 180. But to the great valley of the Ganges can be allowed only 55 inches, and to the Dekan or Southern India, east of the Ghâts, but 24. Singapore, nearly under the equator, has 97 inches, Hong-Kong 79. Buitenzorg in Java claims 150 inches, Cape Comorin only 28, Bombay 162, Ceylon 77 inches. Sierra Leone, with a rainfall of only 87 inches, is deemed one of the wettest places on the African coast. In America the heavy rains of the intertropical zone seem more uniformly developed than elsewhere. At Maranhão the rain of the year amounts to 280 inches, at Cayenne to 108, Pernambuco 106, St. Domingo 100, Caraccas 155, Vera Cruz 183. At Buenos Ayres the annual amount of rain is but 52 inches; Valdivia, in Chile, exposed to the N.E. winds from the Andes, has 120 inches. Further north, for a long distance, the western side of South America is nearly rainless till we reach Guayaquil, where nearly under the equator rain is constant.

In the United States the mean amount of rain is about 40 inches, Florida having 62 inches, and rainfall decreasing towards the north and west. The country adjoining the Rocky Mountains on the east is all ill-watered and to a great extent an arid desert. On the western coast of North America, as on the coast of western Europe, rains grow abundant towards the north, where they are washed by the warm current from the equatorial ocean. Monterey has 12 inches of rain, St. Francisco 22, Fort Vancouver 47, Astoria 86, and Sitka (in lat. 57° 2′) 90 inches.

The British Islands, taken together, have a rainfall certainly not exceeding 36 inches; and this probably much exceeds the collective annual rainfall of the whole of the Old World outside of the tropic. Heavy rains are experienced at certain points on the sea-coast or near mountains. Thus Coimbra, in Portugal (on the face of a steep mountain, the Sierra d'Estrella), has 119 inches, Tolmezzo (at the head of the Adriatic Sea) 95, and Bergen, in Norway (resembling Sitka in situation), 83 inches; but in Lisbon, Madrid, and Barcelona the rainfalls are respectively 25, 18, and 10·5 inches, in Rome and Bologna 30 and 22 inches, and in Christiania and Stockholm 22 and 19. 44 inches may be allowed for the Alps and Jura, and for the mountainous country extending eastwards to Transylvania; but throughout the greater part of Europe rain decreases regularly towards the east and north. In Germany and Poland it may be estimated to be 23 inches, in Sweden 21, in Russia 15, and at Astrakhan, at the mouth of the Volga, only 6 inches. On the western side of Caucasus rain of course increases, and Redut-Kalé, on the Black Sea, at the foot of the mountain, has 67 inches; but beyond the mountains to the south-east Tiflis has but 20, and Baku, on the Caspian Sea, but 13 inches. Further on we enter Siberia, a comparatively dry country. Katherinenburg is favoured with 14 inches of rain, Barnaul with 11; Nertchinsk, at a height exceeding 2000 feet, has little more that 17 inches; till at last, on the eastern shore of the Asiatic continent, we find Ayansk, at the sea-side, with 35 inches, or nearly the same rainfall as Great Britain. On the south of Siberia are great mountain-ranges, on which snow and rain fall in abundance; but beyond them again are wide valleys scantily watered, and desert plains of immense extent on which rain never falls.

In Australia a very scanty supply of moisture is very unequally distributed. Port Jackson receives 82 inches of rain, while

Adelaide has but 21. The northern settlements are capriciously watered by the monsoons ; but nine tenths of the land may be considered an irreclaimable dry desert.

From what precedes, it seems hardly possible to resist the conclusion that the precipitation of rain and snow over the whole earth, in the course of one year, cannot exceed 100 inches, or, in round numbers, 8 feet of water ; and this conclusion tends to prove that the estimates made of evaporation by Lieut. Maury, who assumed its annual amount to be 16 feet, far exceeds the truth.

CHAPTER XVII.

Moisture on the Earth—permeates the ground.—Formation of Springs.—Opinions of the Ancients as to the Source of Springs—all from the Clouds.—Halley's miscalculation of Rain and Rivers.—The sufficiency of Rain.—Underground Reservoirs.—Artesian Wells.—Intermittent Springs.—Steam-Wells from Volcanoes.—The Geysers.—Brine-Springs. Connexion of the Sea with Land-Springs.—Rivulets collected into Rivers.—Basins and Watersheds.—Great elevation of River-sources not Essential.—Velocity and Force of Rivers.—Deltas.—Erosion of Channels.—Cañons.—Deflection of Rivers by the Earth's Rotation.—Improvement of Rivers.—The Kalihari Desert and the River Orange.

Precipitation of rain or snow completes the cycle of changes undergone by water in the course of its circulation. Aqueous vapour from the surface of the earth, and especially from the ocean, forms clouds, which, borne by the winds from their birthplace and widely distributed, pour down on the land in floods. These gathered into rivers flow to the ocean to be again purified by evaporation, and again sent forward on the same mission. Rain falling on cultivated ground penetrates it slowly, and but a little way. A fertile soil readily imbibes and is capable of retaining like a sponge a large quantity of water, so that 18 inches of rain, or above half of the annual rainfall in England, hardly wets the ground, if it be loose mould, to the depth of 15 inches. The humidity thus detained near the surface goes off by evaporation or is consumed by vegetation. But the greater part of the rain that falls sinks into the ground through sand, gravel, or other permeable soil, particularly when gathered on the surface into drains. In truth only pure clay and the most dense homogeneous rocks are absolutely impermeable. Rocks, however, are seldom free from splits or cracks, and limestone in particular is generally cracked in all directions. Thus water finds its way down, and in process of time it can, by corrosion, form even wide passages through hard rocks. In this action it is aided by the carbonic acid mixed with it. In the deepest mines the rocks are humid, and become more so after heavy rains, varying in moisture more or less slowly, according to season, the distance from the surface, and the nature of the intervening ground. Thus water, in obedience to gravitation, flows underground as well as on the surface, though more slowly because more hindered; and as it gathers into pools in hollows above ground, so it accumulates in every subterranean basin found in the less permeable rocks, and there, more or less mixed with the soil, constitutes a permanent reservoir. If it be asked, How far can water descend into the earth? the answer must be that, as temperature increases downwards, there must be a point, at the distance from the surface perhaps of about 9000 feet or less than 2 miles, at which it reaches the heat of water boiling under the pressure corresponding to that depth, and where consequently the water being converted into steam tends to ascend. Thus not a drop of water can be lost. It is confined to the surface of the globe and its vicinity by internal heat.

The water which flows or trickles underground sometimes finds its way to the surface as springs. These, therefore, considered as eruptions of water flowing through the ground merely under the influence of gravitation, may be found at great elevations, but can never occur at the very summit of a mountain. They must be lower than their sources. It is, indeed, vulgarly believed that the Hexquellen or Witches wells on the Brocken (in the Hartz) are on its summit. But in truth they are 18 feet below the highest part of the mountain, and the area of the more elevated crest is amply sufficient to supply them in ordinary seasons. They have, however, at times become quite dry. Springs found on the very summit of a mountain, as those of the Isle Pantellaria in the Mediterranean, must owe their origin to volcanic forces. Steam ejected from the depths of the interior is condensed at the surface and fills the hollows of the rocks. Thus the goatherds water their flocks on the summit of the mountain at the wells filled by the condensation of the steam that issues from the volcano. The hot wells found on the mountain-passes of Thibet, at an elevation of 16,000 feet, have a similar origin.

It was held by Aristotle that all the water that flows on the earth in rivers is of meteoric origin, and derived chiefly from rain or snow. But he believed also that mountains have the power of attracting humidity from the atmosphere. This doctrine was maintained at a later date with little variation by Vitruvius. But it was too simple to acquire ascendency in an age that delighted in subtlety; or perhaps the superior impressiveness of volcanic phenomena may have thrown it into the shade. The opinion long prevailed that springs owe their supply to distillation or vaporization from a great reservoir of water in the interior of the earth. This is clearly the conclusion that might be drawn from the wells on the summit of Stromboli. That springs or rivers cannot be due to rain is proved, according to Seneca, by the statement of all who keep vineyards, that the heaviest rain never penetrates above ten feet in the ground ("Omnis humor intra primam crustam consumitur, nec in inferiora descendit"). The whole moisture is spent in the upper layer and goes no deeper. Among modern philosophers Mariotte was the first or most distinguished of those who assigned to springs a place in the circulation between the atmosphere and the ocean. He calculated that of the rain that falls in the basin of the Seine, not more than a sixth part is carried off by that river, the rest being expended by plants and evaporation. In England, however, Dr. Edmund Halley arrived at a very different conclusion. He discovered, as he thought, that all the rain and snow that fall in this country are not sufficient to fill its rivers. Extending his calculations to other countries, he found also that the great rivers flowing into the Mediterranean do not suffice to make good its loss by evaporation.

Halley's data and deductions on this subject, as far as England is concerned, are now acknowledged to be erroneous; but with respect to the Mediterranean Sea his conclusion is generally accepted.

It is admitted, indeed, that his estimates of the extent of that sea, of its prevailing temperature, and other particulars are far from being correct; but then the correction of his data has no tendency to reverse his decision, so long as his method of examining the question is strictly adhered to. A capital defect in his calculation, however, seems to have hitherto escaped notice. It cannot be doubted that of the vapour raised at any time into the air, a considerable portion falls back again, in the form of dew or otherwise, to the ground whence it arose. On the sea in like manner vaporization and subsidence of vapour both go on incessantly. Their mutual relations are such as are exhibited with exaggerated features in the belt of equatorial calms, where rain falls constantly, while the sea keeps steaming, and a very large part of the product of evaporation, though by no means the whole, is carried off. But in the case of experiments on evaporation, the vapour which once leaves the water-vessel never returns to it and is totally lost, obviously because the orifice of the water-vessel bears a hardly appreciable proportion to the space occupied by the diffused vapour. If for the water-vessel we substitute a sea of many thousand square miles in extent, it is evident that the vapour that rises from it will not be all lost; much of what rises by day will fall back at night. The greater the sea, the less the relative loss; and this being considered, it may well be doubted whether the Mediterranean Sea needs an influx from the ocean to make good its loss by evaporation, and whether the current setting into it be not merely a drift due to the prevalence of westerly or southerly winds or to tide.

The miscalculations of Halley respecting the rains and rivers of England were corrected by Dr. Dalton, who, in 1799, ascertained that the rainfall throughout England amounted to 31·4 inches, or, together with the humidity deposited by dew, to at least 36 inches. On the other hand, he found that the Thames, the basin of which embraces one eighth of the kingdom, carries down but one twenty-fifth of the whole rainfall. The rivers together therefore discharge but $\frac{9}{25}$ of the rainfall, the remaining $\frac{16}{25}$, equal to about 23 inches of rain, being absorbed by the soil and consumed by vegetation. Thus it was proved that the fall of meteoric waters adequately accounts for the constant flow of springs and rivers.

So long as meteorological observations were wanting, it was deemed by many a paradoxical assertion that all the running water on the earth falls from the clouds. Those who controverted that doctrine relied chiefly on some peculiarities observable in springs, viz. the great force with which they sometimes issue from the ground, their occasional high temperature, their saltness or impregnation with various minerals, and in some cases their apparent communication with the sea. But it is easy to perceive that the water of springs may be all of meteoric origin, although in passing through the earth it be so mixed and acted on in various ways as to come forth at the surface with different characters. It may sink, in the first instance, to a great depth till it arrives at a temperature so high as to send it back in the form of steam. Thus rapidly ascending and condensing near the surface, it may come to light as hot water, nearly at boiling temperature, or mixing underground with cold streams, it may give heat to numerous tepid springs. Water may by its pressure promote chemical action producing heat. By dissolving the salts of various kinds that lie in association with the rocks, it is liable to frequent and sensible change of quality. But even when it remains in all respects unadulterated, it may come forth in a manner which to ordinary observers seems unaccountable.

Let us suppose an extensive basin of clay or impervious rock, on which lie strata of chalk, sand, or gravel, likewise concave or depressed in the middle, the central hollow above these being filled up or covered with clay. The rain which falls on this upper stratum does not penetrate it but runs over the surface, collecting impurities till wasted by evaporation. It undergoes no natural filtering and fills no spring. Clay soils, therefore, want good water. But at the margin of the basin, where the underlying gravel and other permeable strata crop out, the rain sinks into the ground and fills these strata, which thus form a reservoir of water beneath the clay. But as they rise at their margins above the central bed of clay, the under surface of this has to bear a hydraulic pressure proportional to the superior height of the water-bearing strata. If, then, a passage be bored through the upper clay, the water will rise through it to the level at which it stands in the highest part of the inferior strata, and the pressure being great while the bore is small, it may shoot up to a surprising height in the first instance. Thus is formed an Artesian well, which is so called from the ancient province of Artois in the north of France, where wells of this kind first came into use. One of the best examples of the Artesian well is that of Grenelle in Paris, on the southern side of the Seine. It was bored with difficulty in three years, through chalk, sandstone, and green marl, to a depth of 1798 feet, or above a third of a mile. The water shot up at first to a height of 112 feet above the ground, and continued for some time to pour out nearly a million gallons daily. The hills of moderate elevation from which the water is chiefly derived extend from S.E. to N.E. of Paris, at a general distance of about 100 miles. The exposed water-collecting surface has an area of about 117 square miles; the enclosed area or reservoir may perhaps have 20,000.

The courses and channels of underground water lie beyond the reach of conjecture; but there is ground for believing that they often have great length and little impediment. It was observed in an Artesian well at Tours that leaves, stems of plants, and ears of grain, tolerably fresh, frequently occurred in it; and these were traced by careful investigation to the Department of Ardêche, above 250 miles distant. But the channels through which are supplied the copious freshwater springs that emerge in the sea have probably still greater length as well as depth. At Bahrein, in the Persian Gulf, the arid shore has no fresh water. This, the hottest region of the earth, has little or no rain. But the population, comparatively numerous, derive their supplies of the necessary fluid from springs in the sea. The diver, winding a great goatskin bag round his left arm, his hand grasping its mouth, takes in his right hand a heavy stone, securely held by a strong line which is tied to the boat. Plunging with this he reaches the bottom quickly. Instantly opening the bag over the strong jet of fresh water, he springs up in the ascending current, at the same time closing the bag. The stone is then hauled up, and the diver, taking breath for a few minutes, plunges again. The source of these very copious springs is probably in the green hills of Omân, 500 or 600 miles distant. Similar springs, fed perhaps from the Alps, exist in the Gulf of Spezzia and at many points on the shores of Greece.

In granitic countries the pools of water collected underground in the hollows of the rocks are generally quite separate. They may furnish many wells or springs, though not one very abundant. But the waters imbibed by the loose and stratified rocks communicate throughout and permeate the whole formation. To such strata, therefore, it is necessary to look for copious sources. If the dip of the strata be observed and also the first occurrence of impermeable rock in the direction of the dip, there, where the two kinds of rock meet, water will be found collected. The phenomena presented by springs vary much with the form and character of the underground passages through which they are supplied. Thus the passage may take the form of a siphon; that is to say, it may be bent so as to ascend some distance and then again descend. In this case it is evident that the water cannot flow through till it has reached the highest point of the passage; but having once gained that point, it will flow down; and if the descending portion go lower than the preceding ascending step, the flow will continue till the latter loses its supply; and it cannot recommence when the supply is reestablished till the water again rises to the height of the crooked or siphon-like passage. The stream from such a spring, therefore, will be intermittent. Another cause of intermittent or irregular flow is the collection of gases in the passage, which baffle, by their compressibility, the pressure of the water. The intermittent springs, once thought miraculous, are many and various; they occur frequently in the Alps. The May-springs, which flow from May till August, need excite no wonder; they are evidently fed by the melting snow and ice. But there is one (the English well in the Canton of Berne) which flows only for a few hours in the morning and again in the evening. In the south of France, at Fontestorbe in the Pyrenees, there is a spring which during the summer months alternately flows for 36 minutes 35 seconds and then ceases for 32½ minutes. In wet weather, however, it ceases to be regular or even intermittent. Near Brest is a well which sinks with the flow and rises with the ebbing of the sea. None of these intermittent springs are perfectly regular, but change more or less with the weather; and some have in the course of years wholly or partially lost their peculiarities, flowing with little or no intermission, evidently owing to the wear of the passages by the flowing water.

In volcanic countries it frequently happens that water sinking in the ground becomes converted into steam, which then rushes up with such force as to throw the superincumbent column of water in jets to a great height. This is well exhibited in Iceland. There, at the foot of Barnefall, springs the great jet called the Geyser, *i. e.* the Fury. The water, thrown up at a very high temperature, holds in solution much silex or flint which is deposited on the ground about the Geyser. In this way has been formed a mound of siliceous concretion, 30 feet high and 200 in diameter; on the top of which, in the middle, is a round basin 6 or 7 feet high, and about 50 in diameter. In the centre of this basin is a circular opening about 9 feet wide, in which may be seen the water, in its moments of rest, perfectly clear with a greenish hue. Its temperature, depending on the length of time that has elapsed since the last eruption, varies from 204° to 170° F. At intervals, varying from an hour and a half to half an hour, the intervals growing shorter as the crisis approaches, the water rises to the basin with detonations, boiling and shooting up small jets to a height of 20 feet. This agitation increases till at last comes a violent eruption, which takes place every 24 or 30 hours. With a thundering noise a column of water, covered with white foam of dazzling brightness, is thrown up to a height of 80 or 100 feet. This is instantly followed by two or three more jets rising to a still greater height. When the last of these has fallen back, all agitation in the basin ceases. At a little distance from the Great Geyser is the Strokkr or Churn, the period of which is from two to three days. Owing to the more regular form of its shaft and orifice, its jet, perfectly vertical, is handsomer and rises to a greater height than that of the Great Geyser, though throwing a less body of water. Boiling fountains with jets of water violently ejected, as in the Geyser, are found also in California and elsewhere, but not on so grand a scale as in Iceland. It is obvious that in these cases the water is ejected by the force of steam, and that the action is intermittent because time is required by the steam to gather force sufficient to overcome the weight of the superincumbent column of water. As the fact of water rising from the ground does not prove that its first source is deep in the interior of the earth, so neither does its high temperature prove that it cannot have previously descended from the surface. When it sinks into the ground, it takes the temperature of the ground. At a great depth and under great pressure its boiling-point is raised; and hence the water in the shaft of the Geyser, at a depth of 60 feet, has been found to have a temperature of 260° F.

The existence of salt and mineral springs was long thought to favour the views of those who deny that the waters flowing over the land all ultimately come from the atmosphere; but careful observation and the progress of chemistry have settled that question. The pure water precipitated from the clouds, as it drains through the ground, washes and dissolves the various salts with which the soil is impregnated, and becomes more or less adulterated by the chemical processes in which it takes a part. It is now known with certainty that copious salt-springs indicate the existence, though not perhaps the immediate proximity, of deposits of salt somewhere in the course of the subterranean waters. In several instances the springs perseveringly traced have led to the discovery of beds of salt. As the solvent power of water is increased by heat and pressure, the deeper the bed of salt, the stronger the brine proceeding from it. Water flowing through metallic ores sometimes undergoes a total change by admixture with acids. Thus a river in New Granada, mixing with sulphuric acid, becomes so sour that it is justly called Rio de Vinagre, or vinegar river. The river Orange, in South Africa, after passing through the rocky tract containing copper ores, is said to be poisonous and to kill the fish. In Algeria is a stream formed by the union of two rivulets—one flowing through a ferruginous soil, and thereby strongly impregnated with iron; the other meandering through a peat-marsh imbibes gallic acid. When the rivulets meet they give birth, by the combination of iron and gallic acid, to a river of true ink. Whatever is soluble in the soil is carried off by the water that flows through it. In Tuscany as well as in Thibet there are springs yielding borax; and in various parts of Italy there are others holding lime and silex so abundantly in solution that perfectly moulded stone figures of alabaster, travertine, &c. may be obtained by intercepting their sedimentary deposits.

Though the sea can never be considered as the source of land-springs, it may yet be so connected with them as to cause them to rise and fall with the tide. When an outlet from the spring happens to be on the sea-shore, the high tide may reach a long way up its channel; and since it checks as far as it goes the descending freshwater current and hinders its overflow, the rivulet above is thereby raised; consequently the demand on the spring that supplies it is diminished. Thus in the military hospital at Lille, about 35 miles from the nearest sea-coast, there is a copious well which has a daily and also a monthly variation. Its maximum discharge during the day, which is nearly double of its minimum, occurs always about eight hours after the high tide on the coast between Calais and Dunkirk.

Springs of water on issuing from the ground in general continue to flow on the surface, running off in rills, brooks, or rivulets, all hastening downwards in obedience to gravitation. The declivities along which they descend must sooner or later merge in a common hollow, where the rivulets unite to form a larger stream, which is again joined lower down by others of the same class, till at length all unite in the mean stream or river at the lowest level. If the configuration of the ground were wholly due to the action of running waters, we should expect to find deep furrows washed out wherever the soil was yielding, and rivulets descending from different directions in nearly straight lines to the central hollow; but perfect symmetry and uniformity are rarely found in the natural features of the earth. Water has not been the sole agent in the formation of valleys.

Convolutions of ground with projecting rocks often turn aside rivers and cause them to exhibit irregularites of directions for which it is difficult to account. But since flowing water must descend, the sources of rivers are always on relatively high ground, and for the most part on mountains. A great river may be compared to the trunk of a tree, being formed by branches, which themselves receive numerous less streams or branches, and these again countless rivulets and springs. The sources of a river being in fact very numerous, while general usage prefers to acknowledge but one, it is not always easy to determine which has the best right to be entitled the principal source. The election of the source and the application of the name often precede the perfect knowledge of the basin of the river, and usage, illinstructed, sanctions erroneous decisions. The Inn, where it joins the Danube, is the greater river of the two; yet the stream formed by their union takes the name of the latter. In like manner the Elb robs the Moldau of the honour belonging to superior magnitude. The Missouri is unquestionably the greatest of the many rivers that combine to form the Mississippi, the name and source of which nevertheless are ascribed to an inferior stream.

The whole tract of country that embraces the tributaries of a river is called its basin. If a line be drawn, including all the sources contributing to a river, it will mark out the boundary of that river's basin, or the area draining into it. Such a line, running of necessity over relatively high ground, marks what is called the watershed of that river. On the further side of every ridge or elevation over which it passes other streams may run off in various directions, and the separation of these several river-systems is traced and determined by the line in question. The term watershed, adopted from a foreign (the German) language and signifying a parting or separation of waters, has this inconvenience, that in English it is liable to misinterpretation, as if it meant the slope that sheds or pours down the water, and not its upper boundary. This remark is the more necessary, inasmuch as even professed geographers used the word "watershed" in no fixed sense.

Though lines of watershed must run along elevated ground, yet they are less absolutely influenced by mountains than is generally supposed. The highest summits of great mountains rarely coincide with watersheds. In chains of mountains the loftiest peaks are frequently in advance of the general range, and the rivers which flow off in front rise in the rear. Their sources are in the midst of the mountains, from which they escape by winding round the greatest elevations. Thus the Indus and Burrampooter rise in the elevated plateaux north of the Himâleh, and break through the mountains to reach the plain. In the Carpathian mountains, the source of the Vistula (which flows northward) is on the south, that of the Theiss (running southward) on the northern side of Mount Tatra. In some instances very important watersheds have little elevation. That which separates the Neva and other waters flowing to the Baltic, or icy sea, from those that go to the Caspian and Black Sea, viz. the Volga, Don, Dniester, Niemen, &c., hardly exceeds the height of 1200 feet. In like manner the boundary between the basins of the Mississippi and St. Lawrence is but feebly marked by elevation, and in time of flood canoes can pass from the one to the other. Again, there is no great height between North Cape and Torneo, or the north polar ocean and the Gulf of Bothnia. The Joliba or Quorra also, perhaps the greatest African river, has its sources among hills apparently not above 1500 feet in elevation. Imperfectly determined limits of different river-basins have been repeatedly observed in the Andes, Norway, Scotland, &c. on broad ridges of high land, with lakes or marshes, sending rivers in opposite directions.

The velocity of a river depends on the declivity or rate of fall in its channel, the depth and volume of water being supposed constant. The declivity and volume remaining the same, the velocity will increase with the depth and freedom of the channel. The greatest velocity of a stream is at its surface, immediately over the line of greatest depth. The mean velocity is about one tenth of the depth below the surface ; but when the wind blows up the stream, the strongest current is much lower down. On the great Siberian rivers the north wind often prevails. The boatmen then seek the aid of the current in this way :—They tie a large bundle of sticks loaded with stones, so as to be inclined to sink. This bundle, thrown into the water and carried down by the current, is prevented by the rope which connects it with the boat's head from sinking to the bottom. Suspended in the strong current, it overcomes the resistance of the wind. At the bottom the river's velocity is least, but most important to be determined, as upon it depends the transport of materials and consequent changes in its channel. If bodies, alike in figure and specific gravity but differing in size, be immersed in water, the larger will be the less easily moved, because their weight increases as the cube of any single dimension, while their surface, which gives a hold to the water, increases only as the square. The larger the body, therefore, the heavier it is in relation to the force acting on it. Consequently the force of a stream depending on its velocity, may be accurately estimated from its power of moving the minerals in its bed. But this rule is strictly true only when applied to bodies alike in figure. Rounded pebbles which roll are more movable in water than sand. The power of river-currents is shown in the following Table :—

	feet.	inches.		
A speed of	0	3	per second can move	river-mud.
„	0	$7\frac{1}{8}$	„	small gravel.
„	1		„	common sand.
„	2		„	coarse ballast.
„	3		„	large shingle.
„	4		„	broken stones.
„	6		„	stratified rocks.
„	10		„	hard rocks.

The fall of rivers generalized and represented in a vertical section would resemble a parabolic curve, with inclination decreasing from the highest fountain to the level of the sea, where the stream flows horizontally. The sources lie generally high up on mountains ; but that is not always the case. Rivers sometimes begin on level and swampy plains, over which they wind slowly at first, till, reaching the slopes, they flow rapidly in the latter part of their descent. In Africa, between the parallels of 12° and 15° S. lat. and the meridians of 20° and 30° E., there seems to be a tract of peculiar character, which, with level surface and thickly matted vegetation, is never furrowed by river-channels. The floods run over it, forming lakes, for the most part temporary, till at its southern edge, where the ground declines, it acquires impetus enough to cut channels and to run off in numerous rivers ; but in general the rapidity of a stream decreases as it descends. The mountain-rivulet tumbles from rock to rock ; it then glides swiftly down the mountain side, moves more gravely as it acquires greater breadth and depth, till it joins the great river in the plain, where, with little fall, it flows majestically in a curving channel, impelled by the pressure in the rear. In the high Alps and Pyrenees rivulets have a fall in general of one inch in a foot. The Danube, in its upper course, falls 26 feet in every league ; lower down, near Ulm, only 18 feet. From Ingoldstadt to

Ratisbon (17 leagues) it falls 7 feet in the league, and below Vienna to Buda only 1 foot in the league. The fall of the river Amazons in the last 700 miles of its course is but one fifth of an inch per mile. A river ceases to be navigable when its fall exceeds one foot in a thousand.

As a river wears away its bed, carrying down large stones, gravel, or fine soil, according to its strength, it is liable to change its character in the course of time. The light sand or clay, easily supported by moving water, is carried furthest and deposited at the mouth of the river, where the descending current is arrested by the sea; it there forms bars and banks, which, accumulating and consolidating, become at last fertile and cultivated land. A tract of this kind, the growth of sedimentary deposits, is called a Delta, that being the name given by the ancients to the alluvial land in Lower Egypt about the mouths of the Nile. Rivers with a long course and little current, or exhausted by canals for irrigation, drop their sediment before they reach the sea, and thus raise their beds. The Nile at the present day is raised considerably above its ancient level in its course through Egypt, and adds little to its delta. The delta of the Po advances at the rate of 220 feet in a year; that of the Mississippi, more widely spread, is annually increased by a mean addition of 262 feet, though its south-west entrance or bar advances at the annual rate of 338 feet. The Danube, Volga, and Ganges have all advancing deltas; but such advance growing continually slower has a certain limit in space, though in time indefinitely distant. The delta of the Rhine (the Netherlands) has long ceased to encroach on the sea, and now rests content with resisting the encroachments of the latter. When the discharge of a river becomes impeded by numerous banks or a delta of its own formation, its level is raised; it spreads out near its mouth, and as at the same time it makes its way through the delta by many channels, its waste by evaporation increases and the current loses power. Thus the excessive diffusion of the stream brings its own remedy.

The sedimentary matter carried down by a river is obtained by the erosion of its bed, and depends, as to quantity, on the force of the stream and the character of the minerals through which it flows. Even the hardest rocks are worn away by the incessant action of water falling over them. The cataracts of the Nile have all sensibly receded. The Falls of Niagara have cut away the rock and formed a deep channel for a distance of seven miles, a work which, at the present rate of proceeding, could not be executed, according to Sir Charles Lyell, in less than 35,000 years. His estimate, however, of the distance excavated has been disputed. In California and New Mexico occur river-beds of the kind called by the Spaniards "Cañons"—that is, pipes or tubes which for hundreds of miles are cut through the rocks to a depth of one or two thousand feet. The rivers in the cañons, overhung by stupendous precipices, are rarely accessible, and nowise conduce to the habitability of the arid plains through which they flow. The formation of these cañons is too singular to be ascribed to an agency so common as that of water. It may be conjectured that as their sources lie in a volcanic country, the water that first flowed through them was strongly impregnated with sulphuric acid.

It has been already shown how the winds, moving in some degree independently of the earth, are relatively to the earth's surface deflected from their course, in consequence of the different rotatory velocities of the successive terrestrial zones over which they pass. Rivers, though more strictly bound to the earth than the winds, are at the same time, since water is much heavier than air, more sensibly affected by acquired momentum; and accordingly, when flowing in a meridional direction and at some distance from the equator, they exhibit the same tendency as aerial currents, though in a much less degree, and in the northern hemisphere, which alone furnishes known examples of such deflection, press on the right bank. This is particularly manifest in the Volga, which flows from N. to S., and in the great rivers of Siberia, flowing from S. to N. The bank which they are deserting is everywhere low land with all the characters of an abandoned river-bed; that on which they press is comparatively high, steep, and abraded. In the Siberian rivers the steep bank with the deep channel close to it is always on the eastern side; on the western side the ground is low, the water shallow. In the Volga, the western, being the right-hand bank, is that attacked by the stream. An eminent geologist (Sir R. I. Murchison) has attempted to account for the steep and elevated western bank of the Volga near its mouth, by referring to the supposed extension of the Caspian Sea in ancient times, which, he says, once washed the western banks of the Volga. But the fact is, that the Volga, in the lower part of its course, is constantly moving westwards. The strongly contrasted characters of its banks are due to causes seen in daily operation, and cannot therefore be ascribed to agencies which ceased some thousands of years ago. It is said that the Nile in Egypt also constantly encroaches on the right (eastern) bank and deserts the left. It can hardly be doubted that the Thames once flowed northward from the Hope through Essex ; but pressing constantly on its right bank and leaving extensive marshes on the left, it at length worked its way through the clay ridge, which, uniting Southend with Sheppey, extended to the Stour.

The impulse given to a river by the earth's rotation is very slight compared with those which immediately determine its course, such as the inclination of the ground, the character of its bed, &c. Consequently it is not surprising if its influence be generally overpowered, or that it should be plainly exhibited only in great rivers flowing in a meridional direction, through extensive level plains and in high latitudes.

Rivers have an importance which can hardly be overrated. Besides furnishing an invaluable supply of pure water for domestic purposes, they may be made to fertilize the ground by irrigation, or to serve the purposes of intercourse by navigable canals. But unfortunately the natural advantages of flowing waters are rarely all recognized by mankind till many of them have been forfeited by neglect. In the Nile we have the example of a river turned to some account at a very early age. It tended to spread a fertile soil over the sands of Egypt, and the inhabitants of that country aided its tendencies till the barren sandy plain was converted into a rich garden. Above Egypt the Nile flows between rocks and sandy deserts raised above the level of the river and less easily irrigated ; yet in various parts of the valley, at Berber, Mahas, and Dongola, where narrow strips of level land extend along the river's banks, water was drawn from the Nile by rude machinery, and the small tracts thus cultivated sufficed to maintain a considerable population. This was the work of a semi-savage people, taught by the example of Egypt and urged by necessity.

Africa seems at first sight to be inadequately supplied with rivers ; an unusually large proportion of its coast wears the aspect of dry desert. But much of this aridity is found, on close examination, to be merely apparent. From Cape Gardafuni to the equinoctial line the coast presents to view for a thousand miles nothing more than an elevated beach and low hills of madrepore ; but behind this screen, at a little distance, extend fertile plains watered by a great river, "another Nile," celebrated by Arab writers, and not wholly unknown to the Greeks, but which has long ceased to reach the sea. Unaccountably this country, which has many claims to attention, has hitherto failed to attract the attention of European travellers. South of the line the coast is sufficiently watered, but at a little distance in the interior rain does not seem to fall in abundance north of lat. 5° S.

Between lats. 11° and 13°, and occupying a width of 20° in the interior, there seems to be a peculiar tract of country liable to inundation, and in which the water flows over the vegetation without cutting channels in the ground, owing perhaps to a certain degree and uniformity of slope. A large share of these copious waters are carried southwards by the river Liambegi ; but this being barred at the Great Falls, or Roaring Vapours, the floods of the river spread a long way southwards over marshy ground. A little further south again commences what is generally thought to be a dry desert ; and in lat. 23° or 24° there is a general complaint of progressive desiccation, and the small streams are said to be rapidly disappearing. The truth seems to be that the underlying rock of these great plains is a soft limestone, into which sinks and disappears any river whose bed has been worn so deep. But a little further to the north-west it has been discovered that extensive tracts without a drop of water on the surface support a population enjoying abundance and keeping cattle fed on water-melons. They draw water for domestic purposes by means of reeds from sucking-holes, the same calcareous stratum which carries off the water from the surface allowing the underground flow of copious streams from the north, the superabundance of one part of the continent thus supplying the deficiencies of another part. Since English colonies are now increasing close to the borders of the country in question, it is as well to point out the hidden treasures which in these boundless plains beneath the tropic only wait to be called forth by the resources of civilization. Canals of irrigation might with the greatest ease be made to flow through what now seem to be waterless deserts.

Again, on the northern frontier of the colony of the Cape of Good Hope, there flows a fine river (the Orange, so named by the Dutch from their princes), not through a sandy desert, but a wild waste of good soil, which wants nothing but water and a little industry to change it into a most luxuriant province. An expenditure very small in comparison with the sums daily thrown away on fantastic projects would easily convert 1000 square miles of the Great Karroo into a most productive wheat-field, for which it seems to be especially adapted by soil and climate. The Karroo contains many thousands of square miles; and the river Orange, which has falls lower down, and though a great river is at times too shallow at its mouth to admit even boats, could not be turned to a better purpose than fertilizing the interior of the Cape Colony. It must, however, be admitted that the improvement in question would be incomplete without the construction of a good road between the river Orange and the sea-coast.

CHAPTER XVIII.

The Ocean—its Offices—moderates Temperature—maintains Humidity—General Depth—Deep-sea Soundings—The Atlantic—The Pacific Ocean.—The Permanence of the Sea—its Saltness—Density—Miscellaneous Contents—Transparency—Colour—Temperature at the Surface—Circulation by Heat—Objections answered—Temperature of its Depths.

THE ocean is for the productive earth the great source of humidity and the moderator of temperature. It checks heat by evaporation, and cold by congelation. With a magnitude corresponding to the importance of its agency, it occupies nearly three fourths of the surface of the globe, or 146,000,000 square miles ; and though divided by land into branches or compartments, it is still a continuous whole, circulating round the globe and from pole to pole. Its chief divisions are as follows :—1. The Pacific Ocean (formerly called also the South Sea), spread out between Asia and America, and from the 60th parallel N., widening southwards till near the equator it embraces 160 degrees, or nearly half of the earth's circumference. 2. Between America on the west, and Europe with Africa on the east, extends the Atlantic Ocean from north to south, with an average breadth of nearly 60 degrees. 3. The seas from the eastern shores o Africa eastward and to the south of Asia are all grouped together under the title of the Indian Ocean. 4. All the foregoing seas merge towards the south in the Antarctic or South Polar Ocean 5. The North Polar Sea, confined for the most part within the 70th parallel of north latitude, communicates with the Pacific Ocean by the narrow opening of Behring's Straits, and more freely with the Atlantic Ocean by Baffin's Bay and the Greenland Sea. But so great is the preponderance of water in the southern hemisphere, where the South Polar, Pacific, Indian, and Atlantic Oceans all meet together, that in a map of the globe projected on the horizon of Falmouth, the northern hemisphere will contain nearly all the land, leaving to the southern hemisphere little but ocean.

The mean depth of the ocean has been assumed on theoretical grounds to be at least four statute (3·52 nautical) miles. But so far as the Atlantic Ocean, with which we are best acquainted, is concerned, that estimate is not confirmed by experience. It is true that Lieutenant Denham found bottom, as he thought, in the Southern Atlantic, between Cape Horn and Tristan d'Acunha, lat. 36° 49′ S., long. 37° 6′ W., with 7706 fathoms, or 8¾ miles. Lieutenant Brooke also, of the U.S. Navy, sounded in the Indian Ocean with 7040 fathoms, or exactly 8 statute miles; and some other instances might be cited of similar deep soundings. But competent judges have refused to rely implicitly on the results of those deep-sea soundings, as the line, being liable to be carried aside by currents, cannot be confidently assumed to descend vertically, and the shock which announces the arrival of the lead at the bottom is at great depths no longer felt.

More recently, however, deep-sea soundings have been made with a care that merits confidence. Between Valentia Island on the south-west coast of Ireland and Newfoundland, the bed of the Atlantic Ocean has been repeatedly examined in order to find a suitable line for a telegraph-cable. The expeditions also of the 'Porcupine' and the 'Challenger' for scientific purposes, and with improved apparatus (the sounding-line being of fine steel wire), have furnished much valuable information respecting the depth of the ocean. We thus learn that the bed of the Atlantic to the west of Ireland presents, with few and inconsiderable irregularities, very extensive levels covered with grey mud, composed chiefly of the shells or exuviæ of the minute organisms that are found in abundance at the surface of the sea. This sedimentary deposit, in its composition, exactly resembles chalk. For three fourths of the distance towards Newfoundland the least depth is 1750 fathoms (nearly two statute miles), and the greatest 2424 fathoms (2¾ miles *). North of this line, from the Hebrides to Cape Farewell, at the southern point of Greenland, the depth is somewhat less, or under two miles. From Greenland to Labrador or Newfoundland it again increases, generally exceeding two

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* 880 fathoms make a statute mile (5280 feet), consequently 1760, 2640, 3520, and 4400 fathoms are respectively equal to 2, 3, 4, and 5 miles.

miles. On the middle of the great bank of Newfoundland the sea has a depth of 40 fathoms, increasing to 80 near its margin. Towards the south the bank sinks rapidly to depths hitherto unsounded. Near St. Thomas's (West Indies) the 'Challenger' found 3875 fathoms, or nearly 4½ miles. Thence northwards to Bermuda the depth decreases, but still averages more than 3 statute miles—the island just named being apparently the summit of a pillar springing from a comparatively narrow base, conjectured by Dr. Carpenter to be formed of coral. From a point halfway between Bermuda and New York, down to the equator in long. 40°, the depth of the ocean is hardly ever less than 2640 fathoms, or 3 miles. In the narrowest part of the Atlantic, between Guinea and Brazil, the lead has frequently descended to 2900 fathoms. From Pernambuco to the Cape of Good Hope, the deep-sea soundings, beginning with 2275 fathoms, end with 2325, after passing over, in the longitude of Greenwich, a depth of 2650 fathoms, or 3 miles. Notwithstanding these great depths, so large a portion of the Atlantic has been sounded with 2000 fathoms or less, as to render it improbable that the mean depth of the whole should exceed 3000 fathoms, or three nautical miles.

The Atlantic Ocean is supposed to be divided into two channels by a submarine ridge, connected in the north with the rocky base of the Azores, and running parallel to the coasts of America. The Dolphin's bank, at a depth of 1900 fathoms, in lat. 20°, may be a part of that ridge, which comes again to the surface in St. Paul's rocks, and bending eastward, reappears in the islands of Ascension and St. Helena. The western channel is thought to be the deeper ; yet the soundings taken in the eastern channel are rarely under 3 miles, and 3150 fathoms have been found east of the Dolphin's bank.

On leaving the Cape the 'Challenger' sailed E.S.E. to Kerguelen's land, at Crozet's Island (lat. 46° 27′ S., long. 52° 14′ E.) found 1900 fathoms, and further on to the S.E. 1975 (the greatest depth met with beyond the Cape), till on the way to Sydney (between lats. 34° and 36°) the lead fell to 2600 fathoms. Towards New Zealand the sea grows shallow, and thence eastward continues so for miles among the groups of coral islands, the depths varying from 150 to 400 fathoms; but near the Friendly Islands 2900 were found.

Further north, however, in the Pacific great depths have been sounded. The government of the United States, wishing to establish telegraphic communication between San Francisco and Japan, sent Lieutenant Belknap, in the 'Tuscarora,' to seek a suitable bed for the cable. In June 1874 this officer left Yokohama on a great circle course to San Francisco; but before he had advanced above 100 miles he sounded in 3427 fathoms, and at the next cast 4643 fathoms, or more than 5 miles of wire ran out without reaching the bottom. Discouraged by this great depth, he retraced his steps to try a new course further north and nearer to land. But here again, about 100 miles from the shore, he found a depth of 3493 fathoms. After another 100 miles the lead descended one mile deeper, or to 4340 fathoms. The sea still continued deepening, and at last the lead descended to 4655 fathoms, the line of steel wire being on this and the two previous casts lost, in all 15 miles. The last-mentioned sounding is the deepest yet made on which reliance can be placed; for the apparatus employed was all of the most perfect kind. Thus disappointed in his hopes of finding an eligible sea-bottom on a great circle course, Lieutenant Belknap resolved to follow the shores of the Japanese and Kurile islands to Kamchatka, thence to strike eastwards along the Aleutian chain, and afterwards to creep southwards along the American coast to Cape Flattery, the most northern point of California.

On this course the greatest depth met with in 1000 miles did not exceed 2270 fathoms. But in lat. 50° 19′ N., long. 159° 39′ E., the lead first met the ground in 3754 fathoms; and again, halfway between Kamchatka and the Aleutian Islands, it fell suddenly to 4037 fathoms, the depth at a little distance to the east and west being 2460 fathoms. From the foregoing statement it may be surmised that the North Pacific Ocean is deeper than the Atlantic. But it remains for future investigation to determine whether the deep soundings found in it be not confined to narrow channels. The ocean-bed of the North Pacific Ocean differs widely from that of the North Atlantic, inasmuch as the latter presents extensive levels, while the former is rugged throughout and abruptly unequal. From the velocity of the earthquake-waves that crossed the Pacific in 1834 from San Francisco to Sydney in New South Wales, it has been calculated that the depth of the intervening ocean can be nowhere less than 2365 fathoms. The Southern Pacific is thickly studded with coral islands, which are likely to rise from a great depth. Between San Francisco and the Sandwich Islands the greatest depth is 2600 fathoms. Near the Admiralty Islands, at Papua (lat. 2° N., long. 142° E.), the 'Challenger' has found 4575 fathoms (about 5 miles), the greatest depth, with one exception, sounded as yet with reliable apparatus.

The British Islands stand on an elevated submarine terrace of considerable extent, which sinks rapidly beyond the 100-fathom line. The North Sea or German Ocean, nearly all within this line, is in some parts dangerously shallow. The North Polar Sea, apparently deep between Spitzbergen and Greenland, is generally shallow near the coasts of Europe and Asia. The depths of the South Polar Ocean have not yet been sounded.

The natural condition of the ocean with respect to permanence has been the subject of much speculation. Some have thought that it must necessarily sink, the ground beneath it yielding to constant pressure. Others have held that it must be raised by the quantity of solid materials constantly thrown into it from the wear and crumbling of its shores. Its rise from this cause was calculated by Manfredi to be 5 inches in 348 years. Hoff, satisfied with less precision, estimates that 1000 years may elapse before the level of the ocean is raised a foot. The geologists, with data no less uncertain, speak in equally positive terms. We cannot tell the distance to which water may penetrate into the ground; but we know that temperature increases downwards, and that water cannot pass the line at which it is converted into steam. It is not the solid mineral formation, but a line of high temperature that confines water to a comparatively narrow seam on or adjacent to the earth's surface. Of this we have abundant proof in hot springs, jets of boiling water (as the geysers in Iceland), and the steam issuing from volcanic craters. But as the earth cools, the line that marks within it the temperature of ebullition must necessarily sink deeper, and the waters on the surface must sink with it. Hence some have calculated that the ocean, gradually sinking, will totally disappear when the perfectly cooled crust of the globe (supposed at present to have a thickness of from 20 to 30 miles) shall have increased to a thickness of 90 miles. Fortunately the progress of geological changes is so slow, that if we must not doubt, we may at least claim the liberty of disregarding them. Speculations of this kind derive no support from historical evidence. Local changes of comparatively little importance have taken place on all coasts. In some places the sea has encroached on the land; in others the shore, increased by drift and deposition, has driven back the sea; but on the shores of which we have the earliest historical accounts (those of Greece and the Greek islands, the strands adjacent to the plain of Troy, the coasts of Syria and Egypt) may be seen evidence of much change, but of none compatible with the supposition of a general change of the sea-level.

Of the collected vapour which darkens the sky as clouds, and is subsequently precipitated on the land as rain or snow, by far the greater portion springs immediately from the ocean. Water in the form of vapour rises in perfect purity. In the atmosphere it imbibes carbonic acid gas and ammonia; but when collected into rivers, it adds to these impurities the still more voluminous impurities of the earth. It washes from the surface of the ground, or carries from the depths to which it penetrates, various salts and organic substances. All that is soluble is borne along by rivers in their downward course and deposited in the ocean. Thus the sea receives a constant accession of salts from the rivers flowing into it; yet the belief that it was originally fresh and owes its saltness wholly to the influx of salt from rivers seems to have little foundation. The predominating salt in river-water is carbonate of lime, which, as well as the silicate, is decomposed in the sea by various organisms. Of sodium chloride (common or culinary salt), on the other hand, which is most abundant in the sea, there exists but a faint trace in rivers not affected by tide.

The following analyses of sea-water are taken from—I. the North Sea (lat. 51° 9′ N.), II. the Atlantic Ocean (lat. 20° 54′ N.), III. the Pacific Ocean (lat. 25° 11′ N.), and IV. the Atlantic (lat. 0° 47′ N.):—

	I.	II.	III.	IV.	
Amount of salt per cent. of water	3·44	3·47	3·52	3·57	(mean of all 3·5).
		Per cent. of salts.			
„ Sodium chloride ...	74·20	76·05	73·47	78·14	
„ Magnesium chloride..	11·04	9·0	11·64	6·54	
„ Potash............	3·80	4·0	3·45	4·33	
„ Sodium bromide....	1·09	1·15	0·87	1·46	
„ Sulphate of lime ..	4·72	4·60	4·60	4·36	
„ „ magnesia	5·15	5·20	5·97	5·17	
	100·00	100·00	100·00	100·00	

Thus it appears that sea-water is not a chemical compound, but only a mixture rendered tolerably uniform by circulation. The salts above enumerated are the prominent and characteristic ingredients found in every analysis. But the bodies held in minute quantities in sea-water or in its products, sea-weeds, corals, &c., are numerous. Silver may be extracted from sea-weed, coral, or in still greater abundance from old ship's copper. Though it may be estimated as forming only the hundred-millionth part of the sea, yet the quantity of it contained in the ocean exceeds at least a thousand times the annual produce of all the silver-mines in the world. Lead and copper may be extracted from the ashes of certain sea-weeds. The presence of arsenic characterizes the incrustations of steam-boilers fed with salt water. No less than 27 elementary bodies have been detected in sea-water by Dr. Forchhammer. Arsenic, omitted by him, makes the 28th. It would not perhaps be venturing too far to conjecture that a few particles of every thing that may by any means be dissolved are to be found in the ocean, and have probably been in it since its first creation.

The observations of Lenz, from which the preceding Table is derived, led him to conclude that the saltness of the ocean in general decreases from the equator to the poles. Herein he is at variance with Dr. Carpenter, who, holding that the minimum of oceanic saltness is found a little north of the equinoctial line, sees in that fact a proof that the equatorial sea is supplied from the poles. And both disagree with Dr. Forchhammer, who finds much salt in polar and the maximum in equatorial water. The sources of uncertainty in this case are easily traced. The water tested for saltness is generally drawn from near the surface; but near the pole surface-water is very salt when the sea begins to freeze, very fresh when the ice melts. At the equator the saltness of the surface varies in like manner with the alternations of heavy rain and rapid evaporation. It may be safely concluded that the sea is at its surface saltest where evaporation bears the greatest proportion to precipitation, where the water, leaving the salt behind, is carried off and not replaced. The maximum saltness of the sea will therefore be found in the rainless zones just above the tropics and near the sources of the trade-winds. The conditions of extreme saltness are wanting near the poles, where there is little evaporation, and about the equator, where there is much rain. It is erroneous to suppose that the solubility of sodium chloride (sea-salt) increases with temperature, or that crystals of salt can be deposited in the ocean. The salt in solution cannot separate from the fluid till the latter is fully saturated; but the sea nowhere contains a tenth of the salt required for its saturation.

Sea-water containing 3·5 per cent. of salt is necessarily heavier than pure fresh water, and has a specific gravity varying from 1·0245 to 1·0288. It dilates also with heat, and so grows lighter. The antagonistic effects of heat and saltness are so evenly balanced in the sea that the struggle between them may last some time, though heat at last prevails. In water at freezing temperature (32° F.) the loss of one per cent. of salt causes nearly the same diminution of density as the addition of 54° Fahr. of heat; but in the ocean the salt never varies in quantity above a third per cent.; consequently salter water may be the less dense and flow over the less salt. In that case it must have a higher temperature. Such differences of density in the strata of the ocean being feeble forces, are doubtless often overpowered by currents.

As Dr. Forchhammer's careful investigations seem calculated to lead to a more intimate acquaintance with the internal constitution of the ocean, their results shall be here added :—

	Mean proportion of salts per 1000 of water.
Atlantic Ocean from the equator to lat. 30° N.	36·169
" " from the north of Scotland to the north of Newfoundland	35·946
" " from Iceland to Labrador	35·391

	Mean proportion of salts per 1000 of water.
East-Greenland current into Davis Straits	35·278
Baffin's Bay and Davis Straits	33·281
North Cape and Spitzbergen	35·347
North of Spitzbergen	33·623
German Ocean or North Sea	32·823
The Kattegat and Sound	15·230
The Baltic	4·931
The Mediterranean from the Straits to the Archipelago	37·936
„ „ between Candia and the African coast	39·257
The Black Sea and Sea of Azof	15·894
The Caspian Sea (Sea of Karasu)	56·814
Atlantic Ocean from the equator to lat. 30° S.	36·553
„ „ from lat. 30° to line adjoining Cape of Good Hope and Cape Horn	35·038
Between Africa and the East Indies	33·868
From S.E. Asia to the Aleutian Islands	33·506
From the Aleutian to the Society Islands	35·219
Patagonian cold current	33·966
South Polar Sea, lat. 77° S.	28·565
„ „ 74° S.	15·598
„ „ 65° S.	37·278
The Red Sea	43·067
Caribbean Sea	36·104
West-Greenland polar current	33·176
East-Greenland „ „	35·278

Lenz concluded that the Atlantic Ocean is salter than the Pacific—the Indian Ocean, as the mean between them, being salter on its western than on its eastern side. But when all the observations made on the saltness of the ocean are compared together, they present so many discrepancies as to force on us the conviction that no general conclusions on such a subject can be safely drawn from a very scanty supply of observations made widely apart in time and place. The saltness of the sea is very liable to temporary modification by rain or ice, the vicinity of great rivers, and by currents on the surface or from the deep. All these influences are effective in proportion as the sea is shallow. If the Atlantic, therefore, be salter, as is reported, on its western than on its eastern side, that may be ascribed to the great extent of shoal sea that girds the eastern coast of the American continent. On the shoal, deep-sea water comes nearer to the surface, and evaporation is less countervailed. That the western side of the Indian Ocean is salter than the eastern, cannot be ascribed to its connexion with the Atlantic, since the current sets from the former to the latter, but rather to the peculiar character of its two arms, the Persian Gulf and Red Sea, both removed from the general oceanic circulation, and the latter fitted by all the circumstances of its position to increase its saline contents. The freshness of the water brought from lat. 74° S. (15·598) might have arisen from the melting of ice. The extreme saltness of that from lat. 65° S. (viz. 37·278) was probably due to sulphuric acid issuing from some volcanic fissure; and the same account might probably be given of still salter water (39·257) of the Mediterranean south of Candia. The East-Greenland current running south-westwards from the polar sea bears such a quantity of salts (35·278) as to dispose Dr. Forchhammer to recognize in it the water of the Gulf-stream returning from its visit to Novaya Zemlya. But the whole sea from the north of Scotland to Labrador is remarkably salt; and surely the western half of this tract can have no connexion with the Gulf-stream. Such a retention of identity in circulating waters appears inadmissible.

Seas which participate little or not at all in the circulation of the ocean may of course differ widely from it in composition. The Red Sea having no rivers to replace its loss by evaporation, is necessarily much salter than the ocean. The Mediterranean communicating with the Black Sea and receiving nine great rivers, nevertheless loses by the evaporation of its ample surface more than they can supply, and is generally believed to be maintained at the level of the ocean by a current setting into it through the narrow strait of Gibraltar. It is therefore salter than the ocean, not merely at its eastern end, or near the Libyan shores, but also towards the west between Spain and the Balearic Islands, and in a less degree throughout. The Black Sea receiving the waters of the Danube, the Dnieper, and Don, besides the numerous torrents that rush down from Caucasus, contains ordinarily less than half the proportion of salts found in the ocean. But the excess above its waste which descends to the Mediterranean is not considerable; and but for the Nile the latter sea would probably be as salt as the Red Sea. The Baltic Sea, supplied by numerous rivers with more water than it loses by evaporation, sends a constant current into the German Ocean, and is but little mixed with salt water. The latter, indeed, can enter it only as drift when strong west winds prevail, or by means of the eddies which move in an opposite direction on the edges of every current; or, finally, its greater density may enable it to creep some distance along the bottom.

The Caspian Sea is filled and refreshed by the great river Volga; but numerous salt streams also flow into it from the Steppes along its northern shores, and the volcanic tract on its western side perhaps contributes to taint it. Hence the extreme inequality of its waters, which, in general little more than brackish, are on its south-west shore, opposite to Baku, and at other points, excessively salt.

Besides the elementary substances above enumerated, the sea contains much viscous matter, proceeding doubtless from the decomposition of the organisms, many of them gelatinous, with which it abounds. To this it owes its tendency to putrefaction. Sea-water, even in the midst of the ocean, is rendered offensively fetid by the stagnation attending a few hours' calm. It quickly taints fresh water also. Each kills the minute organisms peculiar to the other, so that when mixed they increase the seeds of putridity. Stagnant salt water, and still more stagnant pools of mixed salt and fresh water, must be shunned as sources of pestilence. Fortunately calms at sea seldom last long; the habit of the ocean is perpetual agitation.

Sea-water is by all accounts far more transparent than fresh water. In the Caribbean Sea, the North Polar Sea near Novaya Zemlya, and elsewhere, shells and pebbles may be clearly discerned at the depth of 120 fathoms. It is generally assumed that light cannot penetrate beyond that distance in the sea. But that assumption, if well founded, can still be understood only as referring to the light perceptible by the human eye. The creatures that inhabit the depths of ocean have many of them organs of vision well developed; and there is no good reason for believing that beneath 2000 fathoms of water they are in total darkness. When water with ruffled surface ceases to be transparent, it still remains translucid. The superficial stratum that intercepts the solar rays may possibly resemble in its effects the unpolished glass sometimes used to enclose lamps. Stopping the rays of light, it become itself luminous, and presents a great extent of subdued light, instead of intense light from a single point. Thus an eye at the depth of two miles in the ocean, embracing a visual angle of 30 degrees, would receive illumination from a circle of one mile of the watery surface above.

The colour of the deep sea is a pure blue. That of a sea not deep enough to preclude the reflection of light from its bottom is green, varying in tint with its depth and the nature of the ground. It was suggested by Sir Humphry Davy that the ocean owes its colour to iodine, which has in truth been subsequently found in it, though in extremely minute quantity. Some assure us that the blue colour of the sea is due to minute particles floating in it—which may be true, but is not satisfactory, since its occasional turbid yellowness may be explained in the same terms. Some hold that the colour of the ocean is connected with its saltness. They allege that in the salt pans on the shores of the Mediterranean Sea the water is at first green, but, as it becomes concentrated by evaporation, turns blue. This, however, does not explain why the Baltic Sea is blue, though shallower and less salt than the German Ocean. In some cases fresh water attracts attention by its blueness. The Rhone, as it issues from the lake of Geneva, is an instance of this kind. The surface of the ocean is often coloured over tracts of many square miles, and rendered luminous by phosphorescent organisms of different kinds, the description of which belongs rather to Natural History than to Physical Geography.

The temperature of the sea depends for its distribution much on currents, which shall be considered further on ; but prior to and apart from these stands the effect of ordinary insolation. The sun never recedes from its mean position at the equator more than the distance from that line to the tropics (at present 23° 27′). At every other point of its course between the tropics its arrival in the zenith divides unequally the time (half a year) required for the passage from tropic to tropic. The distance between them also is unequally divided by the position of that point; and more heat is lost by the luminary's increased distance at one season than is gained by his proximity at the other. Consequently the maximum of solar heat must be at the equator. This, however, is strictly true only of the sun's action upon the atmosphere. Lower down the solar rays are to a great extent intercepted. The trade-winds sweep the vapour of the tropical ocean towards the equator. The volatile humidity collected beneath the fiercest solar rays is thus quickened and carried off in a constantly ascending current. The heat fully employed in expediting the circulation of moisture by clouds hardly reaches the surface of the earth. The zone of clouds is about the thermal equator a little north of the equinoctial line. The mean temperature of the ocean at its surface, as found by observation and changing with latitude in its different parts, is, according to Kaemtz, as follows:—

Northern Hemisphere.

Lat.	Atlantic Ocean.	Pacific Ocean.
0°	78°·67	81°·6
6	81·26	
9	...	82·9
15	75·57	79·62
30	70·74	71·1
45	57·07	51·25
60	48·2	39·81
75	27·3	

Southern Hemisphere.

Lat.	Atlantic Ocean.	Pacific Ocean.	Indian Ocean.
0°	78°·67	81°·6	80°·74
3	79·3		
15	75·58	74·4	78·41
30	68·3	67·2	69·8
45	52·6	54·5	49·6
60	26·47	31·47	27·58

Let it be observed that this Table professes to give in each case the mean temperature of the year, and therefore higher and lower temperatures may be found at different seasons. The Pacific and Indian Oceans are both warmer in low latitudes than the Atlantic Ocean—evidently because they are screened by islands and coral banks from the icy currents of the South Polar Sea. The Red Sea and Persian Gulf are both filled with the warm water of the Indian Ocean, being fully protected by their situation and comparatively shallow entrances from the cold waters of the south. As the highest mean temperatures in the Atlantic are found in lat. 6° N. and 3° S., the middle of the cloud region may be presumed to lie midway between these points, or in 1° 30′ N. It is obvious that the fall of temperature with increasing latitude is not uniform, but grows rapid towards the poles, and that the southern hemisphere is in high latitudes much colder than the northern. The warmth of the Northern Atlantic is anomalous, and due entirely to an equatorial current.

As the temperature of the atmosphere is in general highest near the ground and decreases with altitude, so that of the sea has its maximum ordinarily at the surface and diminishes with increase of depth. Irregularity in the distribution of temperature is exhibited in the atmosphere chiefly in the region between the surface of the earth and the highest clouds ; in the sea it is found in the upper strata exposed to winds and visited by currents from all quarters. The general decrease of the temperature of the sea from the equinoctial line to the poles seems to be about 0°·866, or thirteen fifteenths of a degree of Fahrenheit's scale for one degree of latitude ; but in fact it is far from being uniform. Currents from the polar circle depress the temperature near the equator (at the Galápagos Islands), and again they carry warmth from the equator to the polar circle (in the North Atlantic).

The temperature of the equatorial ocean being assumed to be at the surface 81°·5, the thermometer, about the equator or in the belt of rains and calms, will fall to 40° at the depth of 300 fathoms, and to 32° at 2600 fathoms. But this is an exceptional case, the approach of cold water to the surface being here attributable to the ascending current maintained under the zone of greatest evaporation by the pressure of the submarine polar currents on both sides. Nearer the tropics, or in lat. 18° north of the equinoctial line, the temperature of 40° is first met with at a depth of about 800 fathoms, and at 3000 fathoms (nearly 3½ miles) nothing colder than 34°. South of the equator the decrease of temperature downward in the Atlantic Ocean is much more rapid, on account of the greatly preponderating influence of the South Polar Ocean. It seems certain, however, that in both hemispheres the water at the base of the ocean is extremely cold; water at 32° has been drawn from great depths in low latitudes; in high latitudes at 28° and even at 26°. Whence, then, comes this cold? It cannot in low latitudes have been derived from the earth. The only explanation that can be given of it is, that the cold water of the poles, sinking by reason of its greater specific gravity, has spread over the bottom of the sea, and forms the base of the whole ocean. And this view is confirmed by the fact that seas not communicating directly with the polar seas, nor with the depths of ocean, are free from ice-cold water. Thus the Mediterranean Sea, communicating with the Atlantic by a strait at one place only 160 fathoms in depth, and admitting therefore no cold water, has, below the depth of 100 fathoms, no water at a temperature less than 54° or 55°, which is the mean temperature of its latitude. Seas like the Red Sea and Persian Gulf, which are by their position perfectly secured from polar currents, are necessarily warm. The Sooloo Sea in the East-Indian Archipelago and many spots about the Philippine Islands and in the Pacific Ocean east of New Zealand have warm water at great depths, because surrounded by ridges of coral which rise above the level of the cold water at the base of the ocean. The degree of cold prevailing at the greatest depths of the ocean has not yet been experimently ascertained, the best protected thermometers having hitherto been in every instance crushed by the pressure at a depth of five miles.

It was till recently the popular belief that the temperature of the sea beneath the surface falls regularly with increased depth till it reaches the point at which water has the greatest density. This point is for fresh water 39°·4; for sea-water it is about 28°. But the distinction between fresh and salt water was then overlooked. It was supposed that the line marking the temperature of 39°·4 was to be found under the equator at a depth of about

7000 feet, and thence ascending came to the surface somewhere between lat. 56° and 60°, and that thence to the pole (all the water having the maximum density) the lowest temperature was at the surface. These views seemed to be confirmed by the observations reported by Captain James Ross from his voyage to the South Polar Sea, and now rejected because obviously incorrect, owing, it is believed, to the imperfection of his instruments. Errors, however, so uniform and systematic could not have originated in casual mistake ; and it is evident that thermometers which found the same temperature at all depths never yielded to pressure. Neither can it be believed that Captain Sir James Ross ever knowingly tampered with the truth. It is more probable that in publishing his observations he relied implicitly on some friend (a philosopher by virtue of his office ; perhaps the secretary of some learned society), who took care to adapt them to the theory in fashion.

As water cools it contracts, its specific gravity increasing. Sea-water varies also in density according to its saltness. Heat makes it lighter, salt heavier ; and it is not easy in any case to calculate the exact effect of these opposing elements ; but the amount of variation in the saltness of the sea is always a very minute quantity. It seems, however, to be generally assumed that the polar sea is less salt than the equatorial. This opinion we believe to be wholly groundless. Near the pole in summer, when the ice is melting, the surface of the sea is covered with fresh water. We are told by Captain Scoresby that in the sea near Spitzbergen the temperature at some depth is generally 6° or 7° higher than at the surface. The obvious explanation of this is, that the fresh water which lies at the surface flows from the ice with the temperature of 32°. The surface-water is light and cold, because it is fresh water just thawed and not yet above the freezing-point. The specific density of polar sea-water cannot be learned from its surface in summer. It is not true, as some imagine, that the solubility of sodium chloride or sea-salt increases with heat. The intertropical ocean is salter at its surface merely because it is subjected to active evaporation, which carries off the fresh water. Again, in the central line near the equator there seems to be a decrease of salt, not because, as some explain it, polar water there rises to the surface, but because in the zone of perpetual rains, where perfectly fresh water may at times be drawn from the trough of the sea, no fair specimen of the ocean can be obtained from the surface. We hear of equatorial water at the pole and of polar water at the equator; but surely, since the ocean circulates throughout, there can be no essential and abiding differences attaching to it at the pole or equator. The relative position of currents cannot be absolutely determined by slight difference of density in the water. The cold may flow over the warm, the denser over the less dense; but where there is no agitation the coldest water invariably goes to the bottom.

That there exists a circulation between the equator and the pole, the water from the former flowing to the latter at the surface and returning from it at the base of the ocean, is admitted on all sides; but whether the cause of it be gravitation or the winds is a point disputed. It is asserted, on the one hand, that the column of water at the pole, rendered heavier by condensation, sinks and moves at the bottom towards the equator. At the surface the loss of level thus occasioned is made good by a flow of water from the equator, which is again supplied from below. This theory is resisted on the ground that gravitation could not accomplish the task here assigned to it—that the difference of level between the pole and equator is very small, the distance between them very great, so that, with a descent of only 4 feet on a line of 6200 miles, gravitation could never overcome the viscosity of water. This is a most ingenious argument, the strength of which lies in the tacit assumptions that underlie it. It assumes that the disturbed level of water can be reestablished only by superficial currents. But the fact is that water by its weight and mobility repairs instantaneously every defect of equilibrium or breach of level. The currents that run on its surface are not so much the direct consequences of disturbance as of settlement. Notwithstanding the viscosity of water, it is impossible to make on its surface a depression so slight as to be permanent. The ocean may be compared to a balance of the finest kind. Its perpetual agitation does away with the effects of viscosity. Every defect is instantly and locally repaired, the waves carrying on the account from point to point till the final adjustment. The inclined plane with a slope of 4 feet in 6200 miles exists only in scientific imagination ; it has no place in nature. The adjustment of level is effected by short steps though propagated far. But in endeavouring to show that difference of temperatures could not so far change the relative heights of the polar and equatorial oceans as to give rise to a current from the one to the other, it is not fair to compare the pole, of which little is known, with the equator, the thermal condition of which is peculiar and widely different from the general characteristic condition of the equatorial region. It would be more candid and reasonable to compare the maximum equatorial heat with the nearest ice-cold sea. Between latitudes 23° and 73° may be found a difference of temperatures double of that found by Mr. Croll between the equator and the pole, and separated by little more than half the distance between the latter points. The same writer assures us that the sea in lat. 36° is 3½ feet higher than at the equator ; perhaps then the slope from that parallel to the pole may be sufficient to overcome the viscosity of the sea. Eager to restrict the sway of gravitation, Mr. Croll asserts that the tide raised two feet by lunar attraction is not again reduced by gravitation to the mean level of the sea, but in six hours "is pulled down by the moon." Herein he is grievously mistaken. It is stated by the highest authorities that the tides on our shores are 2 to 2½ days old. But without adopting the arbitrary date assigned to the birth of the tides, we can safely assert that the tide which reaches the British Islands, coming from the S.W., has turned its back on the moon for 8 or 9 hours before it reaches St. George's Channel, and is no longer under the influence of that luminary. The fall of the tide is a local phenomenon ; the same tide may continue on nearly the same meridian (as, for example, on the east coast of England) for a whole day without being "pulled down by the moon."

Neither can we believe that the equatorial ocean is lower than the North Atlantic, and that there exists a hollow just where the trade-winds unite their efforts to heap up the sea. This mode of proving that water cannot flow from the equator to the pole is clearly incompatible with the assumed slope from the equator to the pole. We cannot, therefore, avoid concluding that there does exist a circulation between the equator and pole, effected by gravitation, and as a consequence of difference of temperature. Since the moving force is weak the circulation is slow, and cannot, till reinforced, be called a current; yet it is not on that account less certain, for there is no paralysis in nature and no force lost.

This conclusion does not exclude the winds from a share in the promotion of the circulation in question. Indeed all available forces seem to concur in aiding it; and perhaps the most important is one which has hitherto escaped notice. It is worth while to consider the effect of the tides on the polar seas. The head of the tide is almost strictly confined to the tropical region, but it draws supplies from the polar seas; and though the lunar attraction is at the poles somewhat diminished by distance, still it is more effectual, because more horizontal. It acts most strongly on the densest water; and thus twice a day it draws the polar sea towards the equator, attracting not merely the surface, but the greatest depths, where there are no winds to countervail it. This constantly repeated impulse can hardly fail to generate a current to the equatorial region.

But to come directly to the matter at issue: Mr. Croll points out how the forced circulation of water in pipes or a small vessel differs from that in the ocean. Cold cannot drive down the polar column of water, nor make it heavier than the equatorial column; "nor can heat be applied to the bottom of the ocean to make the water there lighter, so as to generate an ascending current*. But this," he exclaims, "is diametrically the opposite of what takes place in nature." Here he goes too far; for the fact is that an ascending current is generated in the equatorial ocean, though not by heat applied at its bottom. The sun operating on the clouds in the mid region of the earth raises and disperses them so rapidly as to create an ascending current in the atmosphere; hence comes reduced pressure, which, with heat, calls forth excessive evaporation; and this exhaustion of the surface is supplied by a never-failing current from below.

The ocean may be divided into two great compartments—namely, that of warm water, receiving its heat from the sun and

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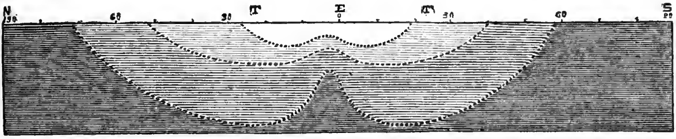
* Climate and Time, p. 146.

lying therefore at the surface, its warmest portion being in the middle or about the equator; and that of cold water, underlying the preceding and reaching the surface only in the polar regions, to which it owes its temperature. The lines of equal temperature drawn through it all sink deeper towards the equatorial region; but the two cold streams from the poles meet in the middle and resist each other's advance; they become piled up and approach the surface of the ocean, where it is rapidly carried off by exhaustive evaporation. Fig. 85 exhibits a section of the ocean between the poles, or from N. to S. The shading of the water increases as temperature diminishes, the regions marked out by dotted lines being the intertropical or torrid zone, the warm temperate, the cool temperate, and that of congelation. The conjunction of the polar streams at the base of the ocean is not at the equator, but north of it, owing to the greater volume of the southern ocean. The depth at which the temperature of 40° may be found is at the northern tropic about three times that at the equator. The cold water, as might be presumed from its position, is collectively heavier than the warm, and constantly presses towards the equator, where it is drawn off and dissipated, while the polar basins are as constantly replenished.

Fig. 85.



Now it is obvious that, if there be near the equator a constantly ascending column of water (and the fact, we believe, is not disputed), that ascending stream, due to the excessive evaporation in the belt of calms, is the mainspring and cause of perpetuity of the circulation between the pole and the equator, which is not the effect of polar cold, nor yet of the winds; for if there were no winds or currents towards the poles it would still continue as the consequence of the rapid evaporation of the equatorial ocean. The existence of this ascending current is frequently recognized by Mr. Croll, who nevertheless loses sight of it in his alarm lest gravitation should supplant superficial ocean-currents, the importance of which certainly does not depend on their exclusiveness.

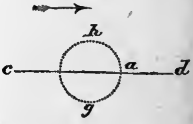
CHAPTER XIX.

Waves, how produced—oscillating Motion—the onward Movement of the Water only apparent.—Form of Waves—Velocity.—Earthquake-Waves effect of Wind—increase to leeward—estimated height—Direction changed by Friction—Depth affected by them—Feelings connected with them.—Tides, how caused—Variations in a Lunar Month—Lagging and Priming—Spring- and Neap-tides.—Establishment of a Port.—Dr. Whewell's Cotidal Lines.—Tides round the British Islands.

Disturbances such as cause vibration in solids produce in fluids undulation, or series of waves, proceeding from the point first disturbed. The waves of the sea appear to be mounds of water moving forwards; but in reality the water in unbroken waves has no progressive motion. It does not change place horizontally, but has a movement at once vertical and oscillatory, which, being propagated along the surface, produces the moving profile of undulation. A cork or piece of wood thrown on the sea is not carried away by the waves. On the crest of the wave it moves a little forwards, but is soon left behind by the wave, and then in the hollow it moves a little backwards, so that with a slight oscillation it keeps its place.

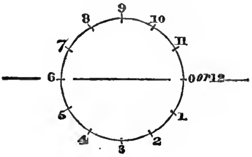
In order to explain the peculiar motion of waves, it is only necessary to show how it may be produced by the revolution of the particles of a fluid near the surface in vertical planes and curved paths, circular or elliptical. If the surface of water be depressed at any point by wind or other force, it rises, when released, above its mean level, and then falls as far again below it; and this alternating movement is propagated all around from the point disturbed, but chiefly in the direction towards which the disturbing force inclines. In order to follow this movement and trace its consequences, let us mark the course of the particle *a* on the surface *c d* (fig. 86). Pressed by the wind from the left, and repressed by the water on the right, it sinks, and sinking

Fig. 86.



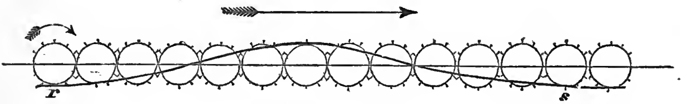
evades the wind, but encounters stronger pressure from the surrounding particles of the water. It is thus forced downwards and backwards to *g*. At this point, sheltered from the wind and left to the reaction of the depressed fluid, it is thrown up to a height (*h*) equal to its preceding depression, and then returns to the line of level to repeat its somewhat circular revolution. The motion of this particle is communicated to all those that follow it in the same direction. All move in similar paths, not simultaneously but in succession; and the line connecting their positions at any instant describes the surface of the water at the same time. The particles being contiguous, their circular paths must necessarily overlap and intersect each other; but in order to avoid confusion in the figures, we shall here assume the particles to be at such a distance asunder as to allow the circles described by them to touch without intersecting.

Fig. 87.



Let us suppose the circular path of the displaced particle to be divided into 12 parts, beginning with 0 or 12 on the right (fig. 87); then 0 and 6 will mark the mean position or level of the water, 3 and 9 respectively the lowest and highest positions of the wave. Let it be assumed also that the time in which the particle passes through one of these divisions is equal to that in which the motion is propagated forward from particle to particle. It is evident, then, that when the first particle has completed its revolution, twelve have been set in motion, each being just one stage of its revolution behind that preceding it (fig. 88). The circular paths of all may be supposed to be divided as in fig. 87. Then all being supposed in motion, the resulting configuration of the surface is easily traced. Suppose the particle at the extreme left to be at the lowest point of its circular path, or 3,

Fig. 88.



Wave-motion.

then that of the next circle will be at 2, in the next at 1, and in the third circle from the starting-point at 0, or the level line. Three circles further on the particle will be at 9, or the highest point; three circles further on it will be again at the level, and with three circles more will reach the lowest point, having thus in 12 revolutions gone through all its phases and taken its position in the 13th circle for a new start. The line drawn joining the immediately successive points in the series of circles in the manner described will obviously represent the profile of the surface, and lines joining all the points, according to the same rule of succession, will represent successive profiles passing one into the other, or the wave as it appears at successive moments of time. Thus is formed an undulation which moves onward, not by an onward flow of water, but by the mere rotation of the particles in a stratum near the surface. What is here demonstrated of particles is obviously applicable to masses of water rolled in lines before the wind.

It is obvious that when the revolving particle is at the highest point of its course (marked 9) it moves forwards, or in the direction of the undulation; and a confluence existing towards that point, the water necessarily rises. Soon afterwards the particle at 3 tends vertically downwards, while that at 9 in the contiguous circle moves vertically upwards. Their motions, therefore, being counteracting and equal, have no effect on the mean level. In the lowest point of the undulation (3), or in the trough between two waves, the motion is backwards; but a little further on the motion of the circling particles is again forwards; and this divergence of the currents necessitates the sinking of the water. The distance from the lowest point of one trough (*r*, fig. 88) to the lowest point of the succeeding trough (*s*) is the length of the wave. The phenomena of undulation being viewed in only one direction, there is no need of distinguishing between length and breadth. The dimension of the wave therefore, measured in that direction, is called by the former name.

The rotation of the particles of water in circular paths has been assumed for the explanation of undulatory movements, because it is the simplest case and admits most easily of clear representation. But the truth is that disturbances calculated to generate circular rotation occur very rarely. The internal motion in waves is generally elliptical, the horizontal axis of the ellipse being the greater, the vertical axis the less, and decreasing downwards till the ellipsis shrinks to a straight line (fig. 89). In shallow water also the ellipsis that generates undulation is much compressed, and the distance between the waves is much increased in proportion to their height. In case of irregular or abrupt disturbance, the ellipse becomes an unsymmetrical unclosed curve (x, fig. 90).

Fig. 89.

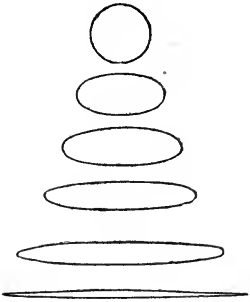
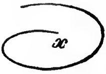


Fig. 90.



The height of a wave depends on the force that gives birth to it; and according to the Brothers Weber, who first investigated the laws of undulation, the disturbance that creates a wave is felt to a depth of about 350 times the height of that wave. This conclusion, however, being drawn from experiments made in narrow cisterns, may not be applicable to the open sea. Theory shows that at a depth equal to the length of the wave, the undulatory motion is but a $\frac{1}{534}$ part of that at the surface. At a comparatively moderate depth, therefore, the ocean may remain little affected by the agitation caused above by winds. Waves increase in height by the persistence of the wind that raises them. When it blows off the land, the waves near the shore attain no great height; but at a distance from shelter, and by accumulation of impulse, they acquire magnitude and velocity.

The velocity of a wave, considered apart from modifying circumstances, is that acquired by a body falling from a state of rest through half the height of the wave. It would increase, therefore, in the duplicate ratio of the height if it were not controlled to some extent by the depth of the water. The connexion between the length of a wave, its velocity, and the depth of the water is shown in the following Table, calculated by Sir George Airy :—

Depth of the water in feet.	Length of the Wave in feet.							
	1	10	100	1000	10,000	100,000	1,000,000	10,000,000
	Corresponding velocity of wave per second in feet.							
1	2·262	5·320	5·667	5·671	5·671	5·671	5·671	5·671
10	ditto	7·154	16·883	17·921	17·933	17·933	17·933	17·933
100	”	ditto	22·264	53·390	56·672	56·710	56·710	56·710
1,000	”	”	ditto	71·543	168·830	179·210	179·330	179·330
10,000	”	”	”	ditto	226·240	533·901	566·720	567·100
100,000	”	”	”	”	ditto	715·430	1688·300	1793·300

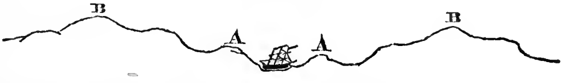
On the 23rd December, 1834, an earthquake ravaged Simoli in Japan. The great waves created by it and propagated across the Atlantic were recorded on the self-registering tide-gauges of San Diego and San Francisco, on the Californian coast. The times of arrival of those waves on the eastern shores of the Pacific, compared with the times of their origin in Japan, justify the conclusion that a wave 217 miles in length may be propagated across the Pacific Ocean between Japan and California, a distance of 4527 miles, at an average rate of 6·1 miles per minute; whence it follows, according to Sir G. Airy's theory and the preceding Table, that the ocean thus traversed has a mean depth of 2365 fathoms, or 14,190 feet.

Waves are ordinarily produced by the pressure of the wind on the sea over a considerable area. The sea is at times beaten down quite flat by violent gales, and becomes for a time a level sheet of foam; but soon regaining its liberty it rises up with an array of waves. To understand the relations of these to their cause, they must be studied collectively. The effect of wind on individual waves is merely superficial. The water being driven forward on the more exposed part, or summit, causes the leeward side of the wave to be the steeper or more abrupt. A strong wind drives the water up into a narrow flake or crest, and this again breaking, mixes with the air and takes the form of foam. To the lofty thin crest and the broken water which crowns it is due all the danger attending waves. A ship rides easily over the greatest unbroken ocean waves, but it must pass through, not over, the ridge of foam that covers the crest. When we hear that a ship has been struck by a sea, we may understand that she has encountered the crest of a wave, which has flung at once many tons of water on the deck.

Since waves increase in speed and height by the persistence of the wind that raised and continues to accelerate them, great swells are most likely to occur far down in the course of constant winds. Hence the S.W. winds of the Northern Atlantic raise their greatest seas in the Bay of Biscay and St. George's Channel. In like manner the N.W. wind of the Southern Atlantic exhibits its force chiefly off the Cape of Good Hope. In these cases the vicinity of land (the shores of Europe in the one case, of Southern Africa in the other) causes by reverberated undulation a shorter, steeper, and more dangerous sea.

The difficulty of estimating the height of waves at sea lies in the absence of any fixed level wherewith to compare them. Captain D'Urville thought that he had seen them reach the height of 100 feet; but in this high estimate he stands alone. Most seamen suppose them to have a height of from 25 to 40 feet. The veteran Arctic voyager, Captain Scoresby, on his voyage to Australia, observed waves the elevation of which above the trough of the sea he calculated to be about 43 feet. Crests of water rose 7 feet higher. But little dependence can be placed on observations of this broken kind; for in a stormy sea different systems of waves coexist, and the space between two waves of a greater system will be occupied by waves of an inferior system; but the seaman can only observe the height of an adjacent wave above the trough of the sea in which his ship lies. He cannot disentangle the mixed systems of undulation, nor compare the lowest trough with the highest crest. He does not perceive the change of level in successive undulations. He may observe the height of A (fig. 91) above the ship's deck, but not that of B above A.

Fig. 91.



When waves roll from the sea into water not deep enough to allow of the internal oscillation propagated from them their speed is checked; and the foremost being most retarded, they come closer together. The wave that feels the ground becomes steeper in front, where it first meets impediment and is piled up, till the crest growing continually narrower at length falls forward as broken water. If the movement of the waves be at right angles to a sloping shore, those nearest the land will be first checked by the friction at the bottom, while those further out will advance with unimpaired velocity in deeper water ; and consequently, as they all hold together, the waves will wheel round so as to face the shore. On every shoal coast and slanting beach, therefore, the waves run directly to the land, or inclined to it at a very small angle.

In perfectly calm weather the waves that flow to the sea-shore have very little height and are wide asunder. They are delicate lines separating broad bands of glassy surface, and exemplify a single system of undulation ; but the wind rising, the sea is quickly covered with waves ; smooth surface vanishes, all is agitation. The furrows between the waves are marked with ripples of a lower order. The waves in the rear pressing those in front, the latter crowd together, raise their foaming crests, and fall thundering on the strand. And here it seems opportune to offer a remark on the immense force exercised at times by the waves of the sea. The power of the wave is obviously due to its weight and velocity, the latter of which elements is seldom adequately estimated. But we are told also that the waves of the sea have moved great rocks and lifted them from lower to higher ground. Such an effect produced by a horizontal force is totally unaccountable ; but let it be observed that the specific gravity of water being as 1, that of granite rock is about 2·5. If we suppose, therefore, a granite rock of 20 tons to be overwhelmed by a great wave, it loses instantaneously by its submergence 8 tons of its weight. The effect is the same as if it received on its base a blow sufficient to raise vertically 8 tons ; and this, added to the horizontal impulse of the wave, constitutes a lifting force.

It is generally believed that the agitation producing waves, or produced by them, is perceptible only to a little depth. This is doubtless true of violent agitation ; but the vibratory motion of undulation reaches to a considerable depth, and any interference with it below reacts on the surface. Hence it is not surprising that the sea breaks on the banks of Newfoundland, where there is still a depth of 400 feet, and that the wave from the Atlantic approaching the west coast of Ireland breaks on the edge of soundings, or in 100 fathoms.

The grandest spectacle of material nature in motion is presented by the sea. Nothing can be more sublime than the immense waves of the ocean, such as are shown in Daniel's drawing of "A North-wester off the Cape," running with the speed of a racehorse. Nothing can be more gently graceful than the flow of the low and widely separated waves that wash the shore in perfectly calm weather. The ripple raised on smooth water by a light breeze wears an aspect of cheerful vivacity. But in all these cases the most important characteristic of waves is, that they are manifestations of a pulsation extending over the globe, and always strictly obedient to a great natural law ; for they are at any one time and place perfectly regular in size and interval, though their regularity is often hidden by complication. We may feel some surprise as well as regret that Milton, when looking round, in his 'Il Penseroso,' for instances of succession as suggesting infinity and serious contemplation, should have rested content with—

> "the far-off curfew sound
> Over some wide water'd shore
> Swinging slow with sullen roar,"

and never thought of the waves rolling in endless succession to that shore, reflecting the moon's rays, and possibly reaching to the horizon, thus figuring in bright lines Jacob's ladder leading to the skies.

A correct knowledge of superficial currents is to mariners most important. In order to find their way through the ocean they must keep a strict account of their course, of the distance as well as the direction run. They must take care to estimate their speed, taking into account the direct effect of tides and currents. If these last be neglected, then the ship's way may be miscalculated, and some risk is incurred. Currents are most dangerous when unsuspected ; hence it is worth while to examine and decide the question whether the waves that roll to every shore have not a propelling power—that is, whether they do not virtually form a current. To prove the affirmative of this question is the object of a volume, written with earnestness, ingenuity, and research, by an officer of the Italian Navy, Commander Alessandro Cialdi. Philosophers have agreed in pronouncing that the undulation of a liquid implies no progressive motion of the mass, but only a change of its superficial outline. There are many, nevertheless, who cling to appearance, and believe the onward motion of the waves to be shared by the water. M. Cialdi exhibits a goodly list of names, many of them distinguished, who seem to favour his views ; but it is evident that his nautical partisans could never have seriously considered the question. Seamen go round the earth, sail in all directions ; baffled by adverse winds, they fully account for their lost time ; but, taken collectively, they keep their reckoning, and reach their destinations with wonderful punctuality. They know their speed precisely, driven by the winds and over the waves ; of the former they carefully take account, but never heed the latter. Waves in a moderate gale have often a speed of 30 or 40 miles an hour. Captain James Ross saw waves to which he assigned a speed of 89 miles an hour. How could a seaman, seeing such waves fly by him, imagine that the water beneath him participates in the velocity of undulation? The silence of the seaman's log respecting the height and direction of waves is decisive proof that waves never interfere with his reckoning.

The best authorities refuse to believe in any connexion between waves and currents. How, then, can it be proved? M. Cialdi does not attempt to offer direct proof of his proposition, but labours to show that on many or most coasts there is an indraught, for which it is impossible to account if it be not the effect of waves. Of the existence of such an indraught he furnishes abundant proof, and the cause of it deserves the careful consideration of those who hold that it cannot be imputed to the waves.

Granting, then, the drift of water towards the shore, let us look elsewhere for its possible and unsuspected cause. It is generally assumed that the surface of water is a perfect level, equally distributed inequalities due to waves being disregarded.

But the truth is that it is seldom level over a wide area; for though water tends to preserve a level surface (that is, to lie at right angles to the direction of gravitation), yet time being required for it, when disturbed, to regain its lost position, its tendency is unable to cope with incessant disturbance. But if the surface of the ocean be not level, will not this affect a ship's reckoning? Lieut. Maury assures us that a boat falls down the sloping side of the broad Gulf-stream. If so, that slope would turn a ship from her direct course. But we are more inclined to believe that the boat, as a buoyant body, would tend to rise to the summit of the watery arch. The waves that fall on a sloping shore leave after them a long line of seaweed and drift-wood, brought there by their clinging to the highest surface and the top of the waves. A coral island in the midst of the ocean and just above its level is continually washed over by the waves, and exercises a sort of attraction on all bodies floating near it, because the sea breaking on its margins everywhere rises above its ordinary level. The island, therefore, receives a proportion of drift far exceeding what belongs to its area, and in a few years it is covered with cocoanut-trees and other tropical vegetation, the seeds being all conveyed to it by the waves. What has been here said of steep-sided coral islands applies much more strongly to banks, or low lands with gradually sloping shores, on which the sea runs up a long way.

Now if there exist in the ocean an impulse, however slight, due to the deviation of its surface from the horizontal line, it is possible that it may, in some situations, increase till it becomes important. Tides are attended with great changes of level, unequally distributed; and on shores in straits and narrow seas the disturbances due to them are often enormously multiplied. It is stated by a well-informed writer that at a certain stage of the tide in the Irish Sea (between the coasts of Wexford and Lancashire) the surface of the sea across from W. to E. rises at the rate of $2\frac{2}{3}$ inches per mile, or 2 feet in 9 miles; the ascent in reality is not uniform, but increases towards the east. The difference of level between the tide at the head of the Bristol Channel and that at Courtown, in the county of Wexford, at the same instant can hardly be less than 30 feet. Such is the difference between opposite shores at high water ; but at low water this state of things is doubtless to a great extent reversed. The tide which leans to the east when flowing into the Irish sea, presses westwards, on the coast of Wexford, when ebbing. It seems worth while to examine whether some unsuspected danger may not lurk in the pressure of tides and currents on sloping shores, which, by raising the water along the shore, creates a lateral impulse at right angles to that of the current. A current runs constantly along the western side of Italy, from the S. to the Gulf of Genoa, the effects of which probably caught the attention of M. Cialdi, who, to account for them, could find no apparent cause but the motion of waves.

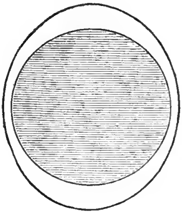
From what has been said, it may be concluded that a wave is essentially a member of a series, obedient to the laws of undulation, and therefore that there can be no such thing as a solitary and disconnected wave.

Nevertheless the name wave is sometimes given to moving heaps of water which have no connexion with undulation and do not obey the laws of waves. A mass of water collected by any means and thrown forward on the sea will, by virtue of its momentum, continue to move till friction and diffusion reduce it to the general level. In narrow channels, where it cannot spread laterally, it may long maintain or even increase its height. Such a heap of water has been styled "a wave of translation." But since it is plainly distinguishable from waves, inasmuch as it is not a part of a series, and in the case of the tides is a moving mass and not merely a form, it may more accurately, and in purer English, be called "a transported billow."

On nearly all the shores of the globe it is observed that the sea rises and falls twice in the course of the lunar day of about 24 hours 50 minutes. The mean interval, therefore, between its semidiurnal risings is about 12 hours 25 minutes. These periodic heavings of the sea are called the tides—that is, in old language, the times or periods of time. On the polar coasts of Russia and Siberia where the movements of the sea are more constantly observable than those of the sun, time is still measured by the tides ; and the distance of a journey is reckoned by the number of tides, or, in the popular language, of waters, required for its completion. The sea attains its greatest height at high water; it then begins to fall, and reaches its lowest point at low water. Then, after a short pause, it begins again to rise; but the ebb or fall is less rapid than the flow or rise, so that the time of low water is not exactly midway between the times of preceding and following high waters, but nearer to the latter. Observation shows that high tide everywhere occurs when the moon arrives at a certain position in the heavens. At Ipswich that position is to the S.E., at London to the S.W., at Bristol in the E.S.E. From this circumstance the philosophers of Greece and Rome concluded that the tides are due to lunar influence; but the nature of that influence remained a mystery till Newton showed it to be a consequence of universal gravitation.

The solid globe and its fluid covering are both attracted by the sun and the moon, with a force varying inversely as the square of the distance from the attracting body. The effect of the attraction on the ocean, however, is not proportional to its whole absolute strength, but to the difference between its action on the centre of the solid globe and on the fluid at the surface. The surface of the sea nearest the sun being more attracted than the earth's centre rises to the attraction: the centre, again, is more attracted than the surface remote from the sun; the sea on this surface, therefore, falls from the luminary or rises in the opposite direction. The effect is the same as if the solid globe were drawn away from the sea on the side remote from the sun, while the sea facing the sun is drawn up from the solid globe. Thus the ocean assumes in the plane of attraction the figure of a spheroid, the longer axis of which points to the attracting body (fig. 92). Now the distance of the sun being about 400 times that of the moon, the difference between its attraction on the centre and the surface of the earth bears a much less proportion to the whole attraction than in the case of the moon; and moreover that whole attraction is but a very small part of what it would be at the distance of the moon. Consequently the sun, notwithstanding the immense superiority of its attractive power, exer-

Fig. 92.



cises less influence on the tides than the moon. Supposing the globe to be all uniformly covered with deep ocean, the height of the lunar tide would be 58 inches, while that of the solar would not exceed 23 inches. The lunar influence, therefore, is to the solar nearly as 5 to 2, or more accurately as 100 to 38.

The ocean, attracted by the sun or moon, tends, as has been stated, to assume the figure of a spheroid ; but in fact that spheroidal figure is never completed. The ocean requires time to adjust itself to the conditions imposed by attraction ; but each luminary moving on, changing its direction and distance from the other, the conditions of attraction to be complied with also continually change, and never wait to be fulfilled. The two imperfectly formed spheroidal tides, the lunar and the solar, or L and S (figs. 93 and 94), always coalesce, the liquid convexity formed by them at T being more broad and flat the greater the angular distance between the luminaries. The solar tide makes its circuit of the earth in 24 hours, the lunar tide in about 24 hours 50 minutes. They coincide on the meridian at the syzygies (fig. 95)—that is, at conjunction and opposition, or the new and full moon. In this case, the tide raised by the more perfect cooperation of the luminaries, called the spring-tide, is proportional to the sum of their forces; and these being assumed to be 5 and 2, the spring-tide will be as 7. The water heaped up at any meridian by the force of attraction is evidently

Fig. 93.

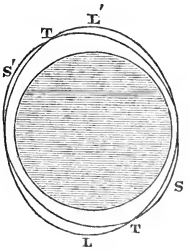


Fig. 94.

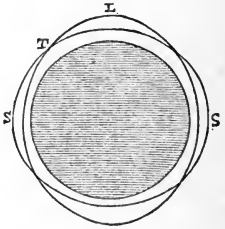
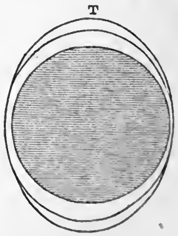


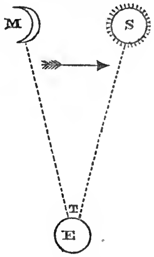
Fig. 95.



drawn from the surrounding ocean to a distance of 90°. Thus a high tide is always followed by a proportionally low ebb. The extremes of low water occur at the time of the highest spring-tides.

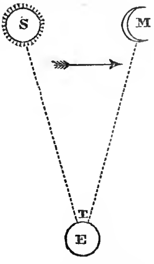
On the day following that of new moon this luminary lags in its diurnal revolution 52 minutes behind the sun, or is about 13° further east (fig. 96). The tide, therefore, formed, not by the coincidence, but only by the close combination of its two elements, is lowered, its highest point being not directly under the moon or sun, but between them, and nearer to the former; and having gone eastward, it occurs a little later than its mean time. This *lagging*, as it is called, takes place from the new to the full moon.

Fig. 96.



In little more than seven days after conjunction, the moon arrives at the quadrature, or 90° from the sun. This is its first quarter. In this position (fig. 94) the attractions of the two luminaries, acting at right angles, counteract each other. The high water of the one coincides with the low water of the other. The result is the neap-tide (T), the relative height of which, being equal to the difference of those raised by the luminaries, is 3. The low water attending neap-tides falls little below the mean level of the sea. After another equal interval of about seven days, the moon, 180° from the sun, arrives at opposition, or is full (fig. 95), and its attraction then coinciding with that of the sun, spring-tides again occur. From the full to the new moon the latter luminary precedes the sun (fig. 97), and high water coming before its mean time is said to *prime*. It then goes on to its second quadrature with neap-tides, and then, completing the lunation, to conjunction or new moon with spring-tides.

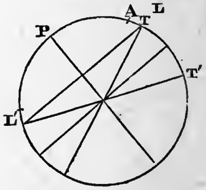
Fig. 97.



Thus within the limits of a lunar month ($29^{d}\ 12^{h}\ 44^{m}\ 2^{s}\cdot87$) the tides pass twice through all grades of magnitude, from springs to neaps, and vary also in the intervals of their succession. The variations already pointed out are increased and complicated by the ever-changing declinations of the luminaries, which, by separating them, modify the results of their combined action. The separation of the sun and moon alluded to in the preceding paragraphs is that measured on the equator; but they also vary in their distance from the equator. The sun, moving in the ecliptic, wanders in the course of the year 23° 27′ north and south of the equator, or through an arc of 46° 54′. The moon, in an orbit inclined to the ecliptic at an angle of 5° 8′, may accordingly range from the equator to a distance of 28° 35′. Thus the luminaries, even on the same meridian, in conjunction or in opposition may be 52° apart, and in that case their widely spread conjoint tide must be much flattened and reduced in height.

The declination of the moon, when considerable, may cause a great inequality in the semidiurnal tides. If the luminary (L, fig. 98), with 28° of declination, be at noon in the northern hemisphere, then the head of the tide (T) will be almost vertically beneath it in lat. 28° N., only 12° from a place (A) in lat. 40°; but the following night, or after 12^{h} 25^{m}, the moon (L′) will be 180° distant on the other side of the globe; and the head of the lunar tide (T′) on the same meridian as A will be in lat. 28° S., or 56° from the point it covered the preceding noon and 68° from A. This diminution of alternate tides is often sufficient in high latitudes to render change in the height of the sea unobservable, so that there seems to be but a single tide in 24 hours.

Fig. 98.



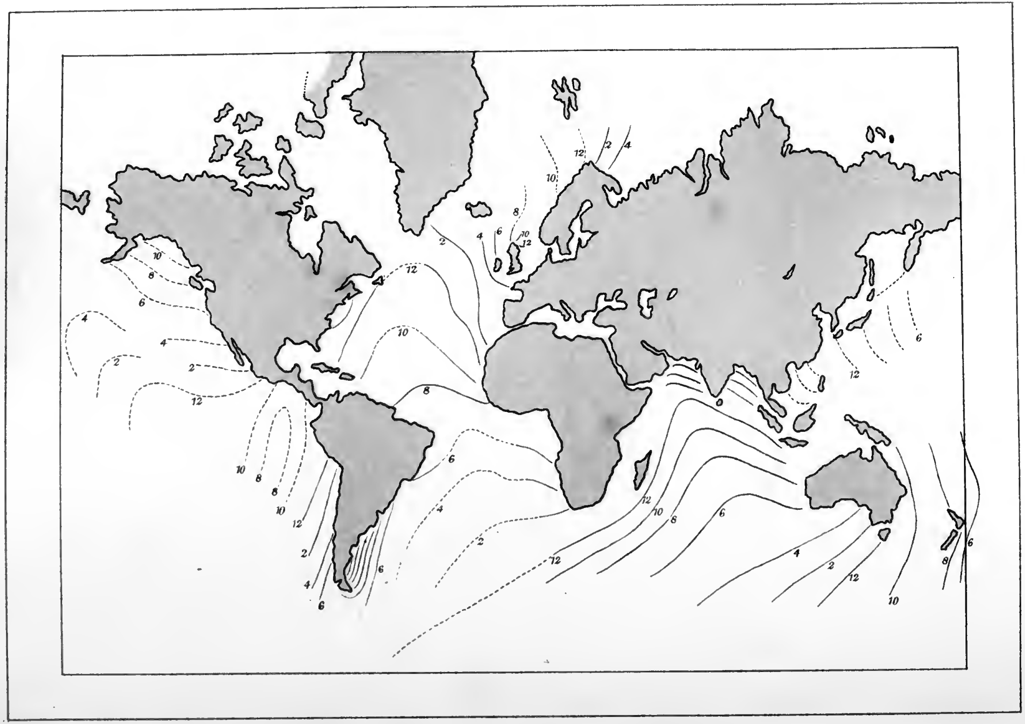
Since the height of the tide depends on the union and strength of the attracting forces, spring-tides are sure to increase as the moon at full or change approaches her nodes, and consequently are highest at eclipses of the sun or moon. If on these occasions the moon be in the part of her orbit nearest to the earth, her influence will be thereby increased; and if the eclipse should take place in January, when the sun also is in perigee or nearest to the earth, then will be combined all the circumstances conducive to a very high tide. If, on the contrary, the sun and moon be widely separated by declination, if the former be in quadrature (*i. e.* at the end of the first or third quarter), and if both luminaries be in apogee or their greatest distance from the earth, then their diminished power will effect but a moderate rise of tide. In all cases the rise of high water is followed by a proportionate fall of low water.

The time of high water being everywhere connected, as already stated, with the moon's position, it is easy to calculate from the lunar movements the time of returning high water. For this purpose it is only necessary to observe the time of high water, or the interval of time between it and noon on the day of new moon. This is called "the Establishment of the Port." The time of high water on any day may then be found by adding to the establishment the time corresponding to the moon's advance in the heavens since the preceding new moon. Care should be taken to find the establishment accurately, to correct for priming or lagging if the observation be not made on the day of new moon, and for the interval elapsing between noon and the moon's passage of the meridian. It is too often assumed that the time of high water is that at which the tide ceases to flow; but in truth high water and the cessation of flow coincide only in bays or inlets where there is no passage for the water. Elsewhere the flow of tide may continue long after the water has begun to fall—that is to say, it flows by, and the water sinks without change of course.

It has been assumed in the preceding paragraphs that the deep sea completely covers the globe, and that the half of it (180°) which faces the moon or sun is raised by the attraction of the luminary till its central zone is changed from a circle to an ellipse, the apsis of which follows the attracting body at the rate of 1000 miles an hour. The highest part or apsis of this ellipse is of course immediately beneath the attraction; and as the paths of the sun and moon are almost always within the tropics, it follows that the tide must be highest in the tropical zone, and thence decrease in higher latitudes. But in fact those conditions, assumed to simplify the theory of tides and render their nature easy of comprehension, do not exist, and their consequences therefore are not realized. The sea does not completely cover the globe. In the northern hemisphere the greater part of the temperate zone is occupied by land, which by its projections divides the ocean into separate basins, the Atlantic having under the equator a breadth of 60, the Pacific Ocean of 150 degrees, narrowing constantly towards the north. Europe, Asia, and Africa, or the Old World, extend from the vicinity of the north pole to 30°, America to 50° south latitude. Thus it is only in the southern ocean and above the 50th parallel that the tide can be collected from 180 degrees, or make the circuit of the earth with unchecked momentum ; but the tide originating in high latitudes cannot possibly have the development of an equatorial tide. Where, then, are we to look for the origin of our tides, which do not flow from E. to W. in the course of the attracting bodies, but come to us from the S.W., or even from the north ?

It was in 1835 that Dr. Whewell first produced the map presenting what he designated "a first approximation to the establishment of cotidal lines." In that map he assumed that the tides in the equatorial region and the Northern Atlantic are propagated from the southern ocean ; and accordingly, beginning with the tide at Tasmania, he drew cotidal lines running northwestwards to India, and to the N.W., N., and N.E. up the Atlantic. But the more he considered the subject, the more he became impressed by the startling facts that there is little or no tide in mid ocean, never more than 2 or 3 feet, and that the cotidal lines on the western sides of Africa and America run nearly parallel with the coasts. He wrote fourteen memoirs on the same subject ; but the result of his persevering study was that he totally abandoned the principle on which his published map was founded, declaring his persuasion that no reliance can be placed on cotidal lines drawn across the ocean (from E. to W.). Nevertheless the cotidal lines of his "First Approximation" continue to be copied, though he subsequently condemned them, his map alone being known, and not his mature views. As he never reduced these to a consistent whole in a second and improved map, we must seek to rectify his first map by omitting whatever appears clearly irreconcilable with his last decisions, and marking in dotted lines what seems to be founded on theory or otherwise doubtful.

Before we proceed to speak of the courses of the tides, it is necessary to direct attention to two preliminary observations.



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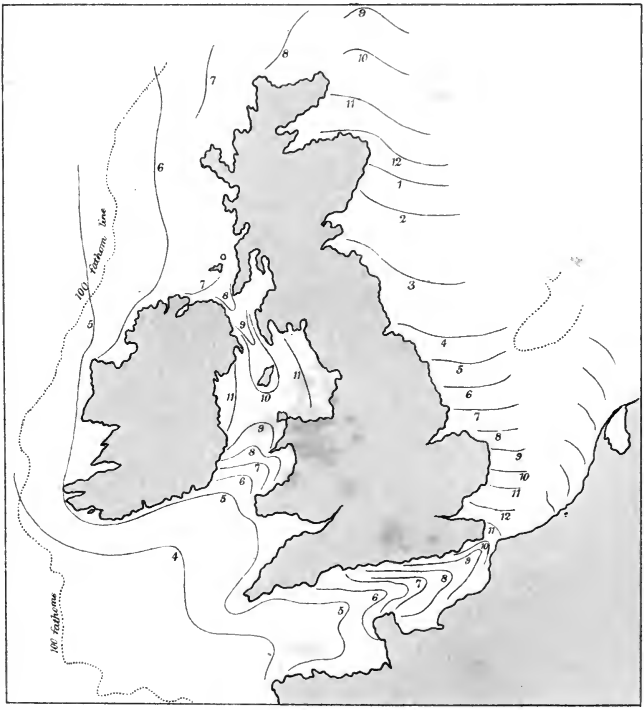
TIDES.

The use of the expression tide-wave seems calculated to engender much misconception. The tide is not so much a prominent mass of water on the surface, as a rapid current in the depths of the ocean, advancing with rapidity of which the surface gives but a feeble indication. But when this deep-seated current meets with opposition and is arrested by land or by an equal current, then indeed it shows itself at the surface, and by accumulation reaches a great height. Again, this current is most rapid in the deepest channel. It is easily checked by friction; therefore when it approaches land, being impeded and held back by the sloping coast, it wheels round, and, like waves, has some tendency to face the shore.

According to Dr. Whewell, who is still our best guide (see Plate of the Tides), the tide that washes the north-western angle of Tasmania, or Van Diemen's Land at 1 o'clock, reaches in 6 hours Cape Leeuwin, the south-western angle of Australia, a distance of 24 degrees. Between those points, therefore, it must be much retarded by the friction of the land; for since it goes round the globe in 24 hours 50 minutes, it ought in 6 hours to pass over nearly 90 degrees. We must suppose, therefore, that further south in the open ocean it has advanced this distance. In 6 hours more it arrives at the southern end of the peninsula of India, and also at the Cape of Good Hope, reaching, however, in a higher latitude the meridian of 40° W., 180° from its starting-point. Near the Asiatic shores it finds shoal water, and consequently requires 6 or 7 hours to advance from Ceylon to the head of the Bay of Bengal, and nearly as many to reach the entrance of the Persian Gulf. The tide which has reached the Cape of Good Hope has, in a higher latitude, advanced 60° further west. It thus faces the Atlantic Ocean, and running north-westwards with reduced speed in four hours arrives at Cape Frio in Brazil. Further south it is so much impeded by the shallowness of the sea that 12 hours elapse before it breaks on the shores of Patagonia. But from Cape Frio it turns north-westwards to the coast of Africa; and in 6 hours from the Cape of Good Hope it appears to touch at once the American coast near Cape St. Roque and that of Africa at Sierra Leone, while in mid ocean it has reached the northern tropic. But in these six hours of progress to the north the moon has gone 90° to the west, and the tide, now deserted by the force that created it and no longer a primary but a derived tide, becomes more superficial and much slower, depending for its direction on acquired momentum, the earth's rotation, the depth of the channels, and form of the adjacent coasts. In lat. 30° N. it begins to bend to the N.E., flowing towards the British Islands, which it reaches in about 16 hours from the Cape of Good Hope.

Having rejected the hypothesis of tides extending quite across the Atlantic Ocean, Dr. Whewell suggested that those tides might be explained by supposing a librating or balancing movement, throwing the sea first to the east, then to the west. This was in fact to restore the influence of the heavenly bodies advancing from east to west, and collecting the waters as they proceeded. Their attraction is doubtless less effective on an ocean only 60 degrees wide than it would be on 180 degrees; yet its power is only abridged, not annulled. It can draw the waters up the western shores of Africa, and again in a few hours collect them on the eastern shores of America. The tide, inconsiderable in the middle of the ocean, becomes conspicuous when accumulated on the shores. In a few hours more the sun and moon passing over the American continent, call a tide to its western shores. This tide and that just described in the Atlantic do not proceed from the southern ocean; nor yet can it be confidently asserted that they are wholly unaffected by influence from that quarter. It cannot at present be stated how far those tides of different origin aid or interfere with, depress or augment each other. The conflict of tides in the Pacific Ocean is proved by numerous irregularities. Dr. Whewell's map contains much information; but it is impossible to determine how far it rests on good observations, and how far on hypothesis.

When we come to consider the tides round the British Isles, we get rid of uncertainty, and have to deal with perfectly ascertained facts (see Plate of the Tides, British Islands). The 4 o'clock tide touching the coast of France near Brest forms a loop towards the English and St. George's Channels; then bending about 100 miles to the west of Ireland, it strikes off northwards. The 5 o'clock cotidal line touches the Irish coast on the west,



TIDES. BRITISH ISLANDS.

Mintern Bros lith.

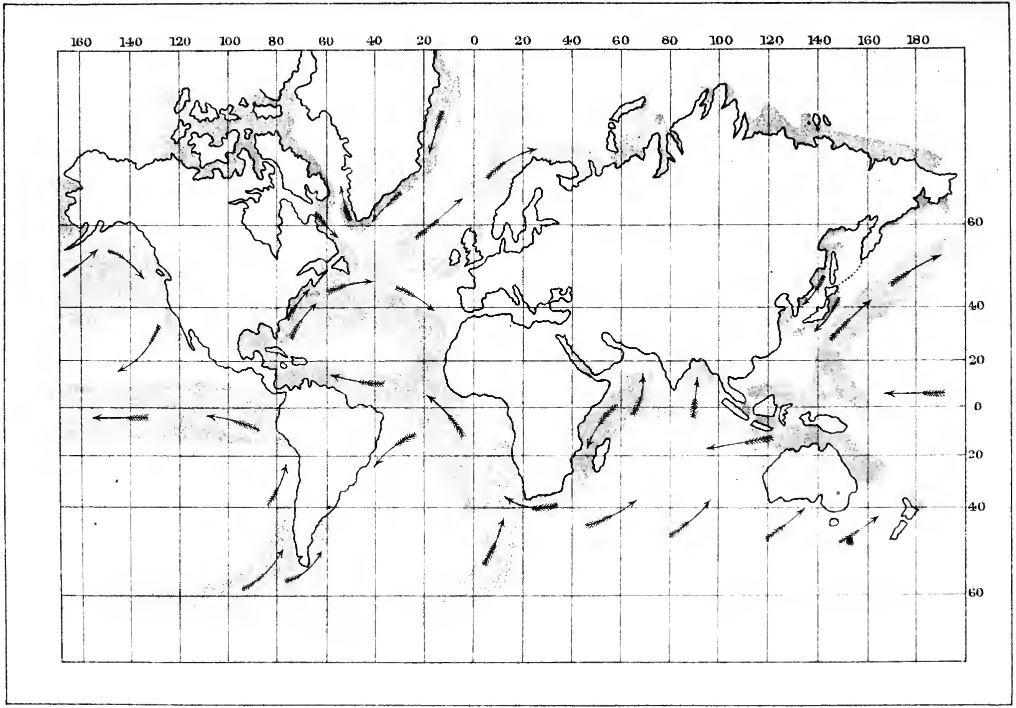
follows the southern coast, crosses to South Wales, and then runs down to the Scilly Islands, so as to complete the circuit of St. George's Channel, and advancing about 120 miles up the English Channel, turns back to terminate on the French coast some 40 miles east of Brest. All the successive tides in the English Channel form narrow loops, the point reached by the tide in mid channel being 100 miles ahead of the point where it meets the land, till at length the 11 o'clock tide joins the Northforeland with the French coast a short way east from Calais.

The 5 o'clock tide, it has been seen, touches the west coast of Ireland. The 6 o'clock tide in the north passes from the shores of Donegal to the westward of the Scotch islands. The successive tides round these northern shores being retarded by the land on the right, wheel round completely, so that the 11 o'clock tide at the north-eastern angle of Caithness faces to the south; the succeeding tides run southwards along the east coast of England, till at last the next 11 o'clock tide from the north reaches the mouth of the Thames, and meets the 11 o'clock which flowed up the English Channel. But these tides are of different ages, that which goes round by the north being 12 hours older than that which flows in the English Channel.

Along the Dutch and Danish coasts the tide advances till it encounters the tide coming from the north. From their collision arises an eddy or circling, to which probably may be attributed the formation of the Dogger bank.

When the tide enters the Irish Sea, its momentum carries it forward to the coast of Wales, and it continues, as in the English Channel, always in mid channel far beyond the points which it has reached on the coasts. Consequently when it has reached the Isle of Man with the 10 o'clock line (4 hours from the entrance of the sea), the coasts of Ireland on which it has, as it were, turned its back, and those of Lancashire which lie in a recess, have not yet felt its approach. But meeting at the Isle of Man the tide of the same age which comes from the north, its progress is arrested, and the accumulated waters flow off on both sides, so that at 11 o'clock high water takes place both at Liverpool and Dublin.

The tides running up the English Channel and Irish Sea, in compliance with the general law, lean to the right; in the latter case especially, because the direction of the current is to the Welsh coast on the right side of the sea. Consequently it rises higher on the right side than on the left. It is higher in general on the French coast than on the south coasts of England, and on the west coast of England than on the eastern coast of Ireland. At Courtown, 40 miles south of Dublin, the rise of tide never exceeds 2 feet. At Kingstown (Dublin) it is 17 feet, at Liverpool 34 feet, Morecambe Bay 45 feet. While running up the channels it passes by the lateral inlets at Bristol and the Gulf of St. Malo without entering them, but when ebbing it fills them; and spring-tides rise at Bristol to 50, at Chepstow, on the Wye, to 60, at St. Malo to 45 or 50 feet; the great height of the tide in these cases being due to the accumulation of the ocean-tide in a narrow recess.



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CHAPTER XX.

Currents, their Origin.—Equatorial Current in the Atlantic.—Gulf-stream. —Strait of Bemini.—Warm and Cold Bands.—Maury's Description.—Magnitude of the Warm Stream, its Course and Limits.—Atlantic Current to the Polar Sea.—Currents the consequences of Disturbance, not Compensations.—Japan Current.—Humboldt's Current—Mosambique—Pacific.—Deflection of Currents.—The Cold Currents famed for the best Fish.—Currents of the Mediterranean, &c.

Heat and gravitation, it has been seen, cooperate indirectly, bringing about a circulation between the surface and lowest depths of the ocean. The winds also, the offspring of heat unequally distributed, give rise to currents on the surface of the seas over which they prevail. The primary or trade-winds, as they are called, produce the most important surface-currents. Blowing strongly and constantly from the N.E. in the northern, from the S.E. in the southern hemisphere, they give to the ocean between them a westward impulse, and the equatorial sea runs in general in a constant stream from east to west. There are still some who maintain that this westward movement of the ocean is due to the inertia of the earth's fluid covering, which does not fully participate in the rotation of the solid globe. But inertia signifies an indisposition to move otherwise than with the solid globe. If we suppose the earth to have been originally in a state of rest, and then suddenly made to rotate, the fluid on its surface must have been forced by friction, gradually and partially at first, yet in the course of time completely, to share its rotatory motion. But in truth there is no reason for supposing that the waters covering the earth ever existed in a state of rest, or prior to the earth's rotation. The effects of inertia would extend over all latitudes on the globe, and give to westward currents a predominance, which has in fact no existence.

In the Atlantic Ocean the equatorial current, running a little north of the equator, strikes the coast of America near Cape St. Roque (lat. 5° 28′ S.), and there dividing, a portion called the

Brazilian current goes southwards along the west coast; but the greater part holds its course W.N.W., till checked by the Antilles on the right hand, it turns westwards, and enters the Caribbean Sea. Still urged forward, it follows the coast, and passes between Yucatan and Cuba into the Gulf of Mexico. This sea, being filled by a constant stream from the torrid zone, not exposed to any influx from the poles, nor cooled by winds from high latitudes, may be considered as a reservoir of warm water; yet cold water at the temperature of 35° found in it at great depths proves that it communicates by some deep channel with the ocean. The warm current in the Gulf of Mexico, compelled to yield to the pressure from behind, runs eastward between the mainland and Cuba, till checked and turned northwards by the Bahama banks, it enters, between Florida and the Island of Bemini, the strait, about 32 miles wide, named from the latter, and thence issues with increased velocity northwards, under the name of the Gulf-stream.

In the Strait of Bemini the depth of the water, reduced by a bar or ledge, varies from 100 to 350 fathoms. On both sides of that ledge the sea deepens; but towards the north, in the course of the stream, are found submarine ridges running parallel to the Alleghanies, and, like those mountains, steep to the west and sloping gently eastwards. Thus the Gulf-stream is divided into several channels; and where these are deep the water is warm, while the shallower water over the ridges is found to be comparatively cold. Nor is this all. The cooler water often manifests a current to the south, directly opposed to the Gulf-stream. These facts have been left imperfectly explained. It is true that coolness generally characterizes water over shoals, because currents flowing over them may occasion the rise of water from considerable depths. The loss of heat also by evaporation at the surface is less easily supplied, and therefore more perceptible the less the volume of water. But the coolness of the water over the ridges could alone be thus accounted for, and not its contrary direction. Now, in fact, cold streams from the shores of Labrador and East Greenland unite to form a current, which runs down close to the shelving shores of the United States, and makes its way through and beneath the Gulf-stream.

But why does the cold current come to the surface? This may be explained by the form of the ridges (steep to the west, sloping gently to the east) and the general law of currents in the northern hemisphere. Both currents lean to the right. The cold streams pressing on the eastern slope of the ridge are carried up by this very inclination; the warm streams going northwards are confined on the right by a steep barrier that effectually represses them.

The course of the Gulf-stream is evidently determined to some extent by the conformation of the ground over which it flows. Hence it winds with the outline of the coast, obeying every bend of the latter, till, in about lat. 40° south of New Brunswick, Newfoundland, and its banks, it turns completely to the east. Close to the shore of the United States runs a very cold current southwards, 60 or 80 miles wide opposite Massachusetts, and growing narrower towards the south. Outside of this flows a warm current in the opposite direction. Then comes another cold band, as it is called; and this is followed by the second warm band, which is regarded as the axis or main branch of the Gulf-stream. It is deep, has a surface-temperature of 81° Fahr., and a breadth in lat. 35° of 30 or 40 miles. The passage into this warm stream, from the contiguous cold current on the west, is remarkably abrupt, so that the line of separation between them has been named "the cold wall." The difference between them (very great at the surface) is said to be still recognizable at the depth of 400 fathoms. Beyond the axis of the Gulf-stream are two more alternations of warm and cold bands, the latter comparatively narrow, till at length the traces of the Gulf-stream are lost at a distance (in lat. 35° N.) of about 450 miles from the American coast.

The occurrence of currents with different temperatures running side by side in opposite directions, of which the Gulf-stream presents a striking, but not a solitary instance, calls for some remark. The opinion held by some that difference in temperature creates repugnance in fluids, so that one body of water will not readily unite with another warmer or colder than itself, has no foundation. The particles of any fluid are to each other in a state of perfect neutrality. When two bodies of water come together, one passes through the other merely by force of momentum. They mix together no further than they are made to mix by friction. They must mingle at their edges where there is contact and attrition; but if they have considerable volumes they may long preserve their respective temperatures. As a current thus forcing its way gains ground only in the direction in which it is propelled, it naturally becomes a narrow streak or band; and this is sure to take place if it meets with rocks on the side towards which it leans. As its velocity diminishes, it may grow wider and deeper by accumulation. Narrow bands may come together and spread out till they occupy a great extent of ocean. In these various phenomena there is nothing wonderful.

Lieutenant Maury, an author who delighted in prodigy, assures us that the Gulf-stream runs up hill. In this there is nothing to be wondered at but the phrase made use of; for nothing more is meant than that the current flows over submarine elevations as well as hollows. But, again, the same popular writer states that the Gulf-stream is roof-shaped or arched, and that a boat left adrift in the middle of it will fall down its slanting sides. This we firmly deny. The transverse section of every current shows some degree of convexity. But in a stream 30 miles broad, and with a velocity of only two miles an hour, the existence of any appreciable convexity is absolutely impossible; and as to the proof offered, it exhibits a strange and not unimportant error into which nautical philosophers often fall; for when the surface of water is disturbed, the tendency of a buoyant body is not to descend but to rise to the highest part of the uneven fluid. If the Gulf-stream had an arched surface, the drifting boat would assuredly settle at the crown of the arch.

The warm current that runs through the Straits of Bemini has a breadth of 25 miles, and an ordinary velocity of 2 miles an hour; its depth is less distinctly stated. Some assign it an average depth of 2000, others of 1200 feet; it may be conveniently estimated to be a quarter of a mile or 1320 feet deep. This being assumed, its discharge of water will be at the rate of 12½ cubic miles an hour, or 300 cubic miles a day. Supposing it never to exceed a depth of 1320 feet, or 220 fathoms, the water that passes the straits in a day will have a surface exceeding 1200 square miles. The temperature of this current is less easily estimated. We are told that in the Straits of Bemini the water, being comparatively shallow, is also cool. But surely it must have had in that strait whatever heat it manifests 10 degrees further north, where its mean temperature at the surface is 80° Fahr., and at a depth of 400 fathoms 70°. It seems, indeed, to increase wonderfully in dimensions and temperature as it advances northwards. Relaxed speed may account in some measure for this growth ; and perhaps it receives accessions from the neighbouring ocean or the equatorial current that flows east of the West-Indian Islands. But we must be careful to disclaim any attempt at extreme precision in estimating the magnitude of the Gulf-stream. The affectation of arithmetical exactness is in such cases delusive. That which is quite certain is that a very large body of warm water from the torrid zone, sufficient to cover 1200 square miles to a depth of 220 fathoms, is daily poured into the middle of the Northern Atlantic Ocean, circulating through its widest part, and spreading laterally, in the first instance, as far north perhaps as the 42nd parallel of latitude. In lat. 40° south of Newfoundland its course is eastward ; and it is impossible to imagine any natural cause for its diversion to the north or north-east. The supposition, then, of a branch going off to the North Polar Sea is purely arbitrary. In obedience to a natural law, the current inclines to the right hand ; consequently it turns southwards along the African coast, and reenters the equatorial zone whence it started. The central portion of the ocean thus encircled by the equatorial current and its offspring the Gulf-stream is the sea of Sargasso, or of sea-weed *. This is an oval space of ocean extending above 20 degrees from E. to W., in lat. 30°. Navigation through it is rendered difficult by the floating sea-weed.

So important is the Gulf-stream to Western Europe, that it is well worth while to understand thoroughly its nature, extent, and operation. It is generally described in terms which seem to

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* The *Fucus natans* bears clusters of berries, having some resemblance to the Sargaço, or wild grape of Portugal.

give it a miraculous character. It runs eastwards, we are told, near the banks of Newfoundland, and then divides, one part of it turning southwards as it approaches the coast of Africa, while another strikes off to the north, and, leaning to the right, flows by the Norwegian coasts into the North Polar Sea. But this division and deviation of the great current is unaccountable. Are there two Gulf-streams? Is not the essence of a current the course it takes in obedience to natural laws? Of the two currents just described, that which flows eastwards and trends to the right hand in obedience to a general law is the true continuation of the Gulf-stream; that which goes northwards at right angles to the preceding, and turning to the left contrary to law, must owe its movement to a different impulse, and therefore cannot be considered a branch of the same stream. To explain the origin of the latter, it will be enough to recapitulate the circumstances of the Northern Atlantic Ocean.

The intertropical ocean is uniformly heated by the solar rays on both sides of the equator; but the predominant influence of the South Polar Sea, owing to its free communication with the ocean in low latitudes and the great extent of its ice-fields, is adverse to such uniformity; and the oceanic zone of greatest heat in the Atlantic Ocean lies 6 degrees north of the equator. This warmest water, flowing westward across the Atlantic, strikes the coast of America for the most part where this extends from E.S.E. to W.N.W., and is compelled to take this course. Caught in the Gulf of Mexico, it turns eastwards, and with a force due to its check and accumulation and the consequent pressure, escapes by the Strait of Bemini. Then, guided by the coasts of the United States and Newfoundland, and spreading out so as to reach even the 42nd parallel of north latitude, it flows eastward and then southward, thus completing the circuit of the Northern Atlantic in the widest part of that ocean and in warm latitudes. Hence the Northern Atlantic, filled by an ever-active equatorial current, is a singularly warm sea with a temperature everywhere exceeding that due to its latitude. The current first set in motion by the trade-winds falls in with the up trades or S.W. winds at its northern limits when flowing eastwards. These very constant winds of course produce a drift and the more easily because there must be, as already explained, a flow of water from low latitudes to the pole. As the ocean continually contracts towards the north, the northward current grows more important as it advances. Since the sea changes its temperature more slowly than the land, its excess of temperature increases towards the north. If in lat. 40° sea and land have the same temperature, the sea flowing northwards will in lat. 50° be warmer than the land, and in lat. 60° very much warmer; and as its relative warmth increases, so does its influence on the climate of the sea-coasts. This influence is, on the northern coasts of Scandinavia, so remarkable, that some peculiar and special cause alone is thought adequate to account for it. Hence the popular belief that the Gulf-stream flows into the North Polar Ocean, though there is no temperature found near the coasts of Norway which may not be derived from any part of the Atlantic Ocean further south. The truth, then, is that a comparatively warm current, which may be called the Norwegian current, runs into the North Polar Sea from the North Atlantic Ocean, which is itself filled with an equatorial current through the Gulf-stream. If there were no Gulf-stream there would be still a current from the ocean into the Polar Sea. That current owes to the Gulf-stream a higher temperature, to the south-west winds increased magnitude. The effects of the Gulf-stream and of the Norwegian current on the climate of Western Europe shall be considered further on.

In many maps showing currents the Gulf-stream is represented running into the North Polar Ocean; but when we look at the charts issued by the Admiralty, founded entirely on observations, and not with a view to support a theory, we find in the ocean to the west of Ireland no trace of a current to the north. A set in that direction first shows itself faintly in about lat. 56°, becomes plain and decided in lat. 60°, and grows stronger as it goes northwards and approaches the coasts of Norway. If it were a branch of the Gulf-stream, it would assuredly be most apparent at its starting-point near the 40th parallel. The Gulf-stream is certainly a most important current, yet there is no need of magnifying it till it becomes a prodigy. It is to no purpose that a very able writer, Mr. Croll, affects moderation, when, in speaking of the Gulf-stream, he adds, " or, if it is preferred, the warm water poured into the Atlantic by the Gulf-stream." The continually repeated assertion that the Gulf-stream flows to the pole, does the work of exaggeration. He claims the merit of being the first to speak of heat in terms of absolute measure; yet it may be doubted whether the reliability of a statement depends on the precision of its terms. It is astounding to learn that the Gulf-stream bears " 77,479,350,000,000,000,000 foot-pounds of energy per day in the form of heat." But let the reader remember that one pound of water gives 19,300 foot-pounds of heat. Let him bear in mind also that there is a very wide difference between increased quantity of heat and rise of temperature, and that that difference is concealed or lost sight of when heat is calculated in foot-pounds. We cannot with four gallons of water at 53° make one gallon at boiling heat (212°). In like manner the equatorial ocean at 80°, though doubled, will still be only at 80°. It is true that, by wider diffusion and copious reparation of loss, the increased quantity of heat will cause some rise of temperature; but that increase will bear no relation to the arithmetical ratios exhibited if the account be kept in foot-pounds. Sea-currents diffuse heat by means of vapour and the atmosphere; and it is perfectly ascertained that warm vapour may be conveyed from a great distance by winds without the aid of currents. Mr. Croll, therefore, whose views as to the effects of equatorial currents are in general perfectly just, goes too far when he asserts that without them the earth would be uninhabitable; the equator, he thinks, would be too hot, the polar regions too cold; but he forgets the further consequences of such a change. Problems of physics often involve so many points for consideration, that the zealous advocate of a theory easily loses sight of those which do not serve his purpose. But if there were at the equator a narrow zone of boiling water, the poles would doubtless serve as condensers, and streams of steam or vapour at a very comfortable temperature would doubtless flow to them continuously through the atmosphere.

When a current runs through inert water, it creates by attrition at its borders an eddy or series of eddies which give to the water beyond them a tendency to run in the opposite direction. Thus one current begets another. But doubtless currents may in general be considered rather as superficial symptoms of compensation effected, than as necessary means of effecting it. If we dip a vessel into a cistern to draw water, the fluid follows the vessel as it is withdrawn, and the level of its surface is reestablished the instant that the vessel quits it; there is no gap left to be filled by currents at the surface. In like manner the weight and fluidity of the sea suffice to repair instantaneously any local loss or depression; and if currents are produced on the surface by the disturbance, they make their appearance when no longer needed; they chase one another on the surface merely to show the quick sensitiveness of fluids whose equilibrium is disturbed. But as there is a flow of warm water to the pole, so there is a flow of cold water from it. This is made manifest by the icebergs carried southwards in spring against the current at the surface, when the extreme cold of the polar winter begins to give way to the approach of summer. The cold ice-bearing currents leaning to the right run down southwards by the coasts of East Greenland and by Labrador, on the western side of Baffin's Bay. Between Western Europe and Greenland warm and cold currents are frequently met with, intermingled in narrow bands; but in all cases (adhering to the general law) they lean to the right in the northern hemisphere, those going northwards (the warm currents) pressing eastwards or on western shores, those flowing southwards (the cold currents) creeping along eastern shores. When split into bands by the nature of the bottom and intermingled, they go, if possible, each to the right; and in channels among the Shetland or Orkney Islands the warm current takes the eastern, the colder polar current the western side.

The portion of the equatorial current in the Atlantic Ocean which turns southwards near Cape St. Roque on the coast of Brazil continues to run at some distance from the continent, till, being gradually deflected to the left hand or east, it recrosses the Atlantic in about lat. 33° S. and disappears. Originally weaker than the branch that flows northwards, it also encounters more vigorous trade-winds.

In the Southern Pacific the current best known is that named from its discoverer, Humboldt's current—a cold stream of great magnitude, which, flowing north-eastwards apparently from the south pole, strikes on the western coast of the American continent at its southern extremity, and flows along it nearly to the equator, when it turns westwards or sinks beneath the warm waters of the equatorial ocean. A branch of this polar stream runs eastwards by Cape Hoorn into the Southern Atlantic. It is to the influence of this cool current that Peru owes its moderate temperature and humid mists. In lat. 12° the temperature of the sea next the land falls short of that of the adjacent ocean by 7° Fahr. A cold stream, supposed to be connected with the preceding, runs along the Californian coast, and reduces the mean temperature of San Francisco by perhaps 8° Fahr. In the neighbourhood of the Galápagos Islands warm and cold currents may be found not far asunder. We are told of warm as well as of cold currents on the coast of California; but it is not clearly stated how far they are constant, or by what standard of temperature they are described.

The equatorial current that runs westward into the Indian Ocean meets no resistance after passing through the Indian archipelago till it reaches the eastern coast of Africa. There, caught in the Mosambique Channel between the island of Madagascar and the continent, it becomes impetuous, and has at times a velocity of 8 miles an hour. Further on it shows itself as the Agulhas current off the Cape of Good Hope. There it meets with a cold current from the south or south-west, and the traces of it become obscure. Some believe that it goes northwards to the equator; but this is doubtful. The warm and cold currents probably intermix and efface each other.

The trade-winds, it must be remembered, do not approach the western shores of Africa, which almost everywhere attract sea breezes—that is, westerly winds. The land draws the trade-winds from their course, and changes them from north-east to north winds, till at a distance of 200 miles from the coast, they blow without restraint to the south-west. Hence there is a margin of the Atlantic Ocean on the west free from the sway of the trade-winds, and which grows wider where the coast of

Guinea runs from west to east. Here, probably owing to the reaction of the ocean-currents uniting to flow westwards, to the head of water raised between the trades, and to the strength of the sea breezes, a narrow current runs eastwards to the Bight of Biafra, from which it takes its name.

The course of the equatorial current in the Pacific differs in many respects from that traced by it in the Atlantic. At the side where it originates, along the western coast of America, lofty mountains (the Andes) check the movements of the atmosphere. A very cold current from the south (the Peruvian, or Humboldt's current) chills the equatorial waters; and on the east the ocean meets not so much with obliquely placed coasts to turn it aside as with barriers of coral reefs and islands to repel it altogether. At the same time its great width favours the development of many irregularities. Hence it is that the equatorial current in the Pacific might be described as two tropical currents flowing westwards between 18° S. and 24° N., with a counter current like the Guinea-stream running eastwards between them in latitudes 4°–10° N. But these currents have not the strength and constancy found in the Central Atlantic. In the western half of the Pacific Ocean, where the trade-winds often give way to monsoons, the currents are liable to change.

The equatorial current does not reach unchecked the Asiatic continent. Many degrees further east it encounters the banks of coral which fringe or support the shores of Australia, New Guinea, the Philippine Islands, and extend further towards Japan. In the numerous straits or channels by which it makes its way among the islands, its direction is varied and its force lost; the outer portions alone retain some importance. The most northern part of the current reaching the shores of the Japanese island Niphon is turned northward, and thus plays in the Pacific a part somewhat similar to that of the Gulf-stream in the Atlantic Ocean. Bending continually to the east as it ascends into higher latitudes, the Japanese current, as it is called, flows at a distance of one or two hundred miles from the Kurile Islands and coasts of Kamchatka; then due east south of the Aleutian Islands, till, approaching the American coast, it takes a south-eastern course, and reaches the latitudes of British Columbia as a warm current. Here it seems to meet the cold current from the south, which chills the climate of San Francisco. It turns therefore to the west, so as to enclose a small sea of sea-weed like the Sargasso of the Atlantic. From the southern borders also of the equatorial current proceeds a stream southwards down the coast of Australia, and gives warmth to the sea between the latter and New Zealand. This current differs from the Gulf-stream, inasmuch as it appears to be an inferior portion of a current generated further south than the equatorial stream of the Atlantic. Again, the form of the latter ocean allows the current to flow as it is impelled, so that unhindered it carries its heat into the polar basin. But in the Pacific the current is compelled to turn southwards, and being thus retarded and forced to mix with the deep is much cooled. From within the Aleutian Islands and the Bay of Okhotsk, cold currents fed by frozen rivers of both the Old and New World flow south-westwards between the warm stream and the Asiatic shores. These cool waters, like those from Baffin's Bay on the coasts of the United States, produce the finest fish.

The communication of the North Polar Sea with the Pacific Ocean through the narrow and shallow Behring's Strait has little effect on the latter. The slender peninsula of Alyaska and attached chain of islands form a complete barrier between two widely different climates, and separate the warm water carried by the Japanese current from that of the strait and the ice-bearing streams that flow into it. The cooling office of the Arctic Ocean thus devolves on the sea of Okhotsk, which reaching to lat. 63° N. and locked in by the peninsula of Kamchatka on the north-eastern coast of Siberia, the coldest region of the globe, collects the ice or the waters of frozen rivers all the year round. From its most northern bays flow three cold currents, viz. :—one nearly southwards, along the western side of Kamchatka and the Kurile Islands ; here it is joined by a cold stream descending along the eastern side of Kamchatka ; and flows as the Kurile current close to the eastern shores of the Japanese islands Yesso and Niphon, while the Kuro Siwo, or warm Japan current, runs north-westwards at a little distance further east, these two currents come into contact near Cape Daiho Saki (lat.

35° 30′ N.), where the warm stream predominates and the Kurile current disappears. A branch of the warm current flows also on the western side of Japan, and passing through the straits of Sangar between Yesso and Sakhalin, encounters a branch of the cold stream, causing a dangerous sea with thick fogs and frequent storms. Another current runs from the most northern inlet of the sea of Okhotsk close along its Siberian shores, constantly sweeping down fragments of ice ; while a third current washes the shores of Sakhalin, creeps between it and the continent, carrying off to the south the ice brought down by the Amur, a river which in the latitude of the Mersey (53° N.) is ice-bound for nine months in the year. This cold current continues its course to the southern end of Corea, where it sinks beneath the warm stream or Japan current.

The Japan current resembles the Gulf-stream, inasmuch as, being the offspring of the great equatorial current, it flows north-eastwards, carrying warmth to the Northern Pacific as the Gulf-stream does to the Northern Atlantic ; but in volume and high temperature it bears no comparison with the latter. While the Gulf-stream is turned eastward in lat. 40° by the banks of Newfoundland, the Japan stream flows beyond the 50th parallel of north latitude, mixing with cold currents, so that though recognized by good authorities as a warm current off the coast of California, it is not always so described. The influence of the great Peruvian cold current extends even to California during half the year. Indeed the only portions of the Pacific Ocean quite free from streaks of cold water are those well-studded with clusters of coral islands, and protected from the intrusion of cold polar water, probably by steep walls of coral.

It deserves to be remarked how invariably is obeyed the rule derived from the rotation of the earth, that currents must incline in the northern hemisphere to the right, in the southern to the left. Whenever in the northern hemisphere a polar and equatorial current flow side by side, the former moving southwards leans on eastern coasts, the equatorial or warm current going northwards on western coasts. Thus a cold current creeps down the eastern coast of Kamchatka, and also along the shores of the sea of Okhotsk to the peninsula of Corea, and again from the sea of Pecheli down the coast of China. Outside of this a warm current presses on the western coast of Japan, while on the eastern coast there flows another cold current, and to the right or east of this again is the Kuro Siwo (black stream), or warm Japan current. In like manner the East-Greenland and Labrador currents cling to the shores to which they owe their names, and follow closely the shores of the United States, while at a little distance to the east the Gulf-stream bends off to the right. These cool streams on the banks of Newfoundland, the shores of Labrador and the United States, and on the eastern coast of Japan are famed for the excellence of their fisheries. In the warm seas of the Indian archipelago the fish are no less abundant, but far less palatable. But the fish that frequent the cool waters of the temperate zone seem to be impatient of ice and extreme cold. It is related that on the shores of Labrador, in the Gulf of St. Lawrence, the fish at times crowd together in such a manner that multitudes of them are crushed to death. This is plainly incredible. Crowded together, asphyxy or want of air would be more fatal to them than pressure. But whence the pressure? On the coasts of Labrador all the rivers descending to the sea bring ice-cold water. At a little distance from the land icebergs frequently pass up the Gulf. The shoals of fish are doubtless often caught between the train of icebergs and the frigid waters from the land, and fleeing from congelation crowd together in the manner described. On the coast of Norway also are streaks of cold water, determined not by currents, but by deep channels filled with dense polar water; and there too, according to the reports of fishermen, the fish are often so closely packed together, that an oar driven down into the shoal will stand upright for some minutes.

Since currents in the southern hemisphere bend to the left, it is evident that the Peruvian or Humboldt's current, which strikes on the western coast of South America at its southern end, must come originally from the west. In the high latitudes of the southern hemisphere the impetuosity of the elements is little checked by land, and the west wind has always nearly the force of a gale. The drifts created by it soon become strong currents, on one side sweeping the perpetual ice, on the other (the left side) spreading out with a change of course. The Peruvian current has been found to have a depth exceeding 900 fathoms, and probably equals in magnitude if it does not exceed the Gulf-stream. The cold current met with on the west of Africa, near the Cape of Good Hope, and those occasionally visiting the southern coasts of Australia and New Zealand, may be all considered as deflected branches of the drifts caused by the west winds that career in front of the ice-cliffs round the southern pole.

It now only remains to say a few words respecting the few currents that flow into or out of inland seas communicating with the ocean. The Mediterranean Sea is said to lose more water by the evaporation of its ample surface than it receives from the numerous rivers flowing into it. It would continually sink therefore, so long as the evaporation from its surface exceeded its supplies, if the deficiency of these were not made good from the ocean. A current sets into it from the Atlantic, which re-establishes the level of the sea; but the remote part, which has lost fluid by evaporation and retained the salt, becomes now the heavier, and in the course of circulation moves at the bottom towards the ocean. Thus in the Straits of Gibraltar there is a surface-current running in chiefly at the south side, and also an under-current running out at the north side, both varying much with the tides, but the former predominating. The Black Sea receives from the great rivers that enter it a supply far exceeding its evaporation. A current therefore runs from it through the Bosphorus and Hellespont to the Mediterranean; but this does not prevent the salter and heavier water of the latter from penetrating by an under-current to the Black Sea, which would otherwise become quite fresh. Here, again, we see the rule of direction strictly adhered to. The current entering the Mediterranean goes to the right along the coast of Africa, and then turning north by the coasts of Syria, returns following all the sinuosities of the Ægæan and Adriatic seas. When we are told that the sea is salter between the coast of France and the Balearic Islands than south of the latter, we must remember that it is the older Mediterranean water, and has lost much by evaporation since it passed in on the southern side.

In like manner the exhaustion of the Red Sea is compensated by an indraught from the Indian Ocean, while a minor stream of salter and denser water issues from the Strait of Bab el Mandeb beneath the inflowing current. In the Baltic Sea, on the other hand, the supply from rivers far exceeds the loss by evaporation ; and consequently a current from that sea flows incessantly into the German Ocean. But the heavier sea-water is still able to penetrate some distance as an under-current ; and the Baltic with all its rivers is nowhere perfectly fresh.

Called into existence by the ever-changeful winds, and liable therefore to vary with the temperature and pressure of the atmosphere, currents are often reported which have no prolonged existence. Many observations are required to determine the constancy of a current. Even those most constant are at times interrupted ; and though the navigator ought to be on his guard against every suspected current, he ought not to trust implicitly all that is taught on the subject.

CHAPTER XXI.

Congelation in Fresh Water—in the Sea.—Thickness attainable by Ice.—Varieties of Sea-Ice.—Source of Icebergs.—Limits of Polar Ice.—Grounding of Icebergs—Distance reached by them towards the Equator.—Snow, its Forms—Density—Limits at Sea-level.—Snow in the Sahra.—Good Effects of Snow.—Perpetual Snow—Conditions determining its Height.—Table of Altitude of the Snow-line.—The Line of Congelation different.—Disadvantage of Ice and Snow.—Perpetually Frozen Ground.—Ground-Ice.—Iceless Cold Lakes.—Congelation fatal to Fish—and to Animal Life in general.

WATER, like most other bodies, contracts as it cools, its volume diminishing about a four thousandth part for every degree of Fahrenheit's scale. This change, however, takes place only within certain limits, the law of dilatation and contraction losing its force near the temperatures which induce change of state. Water, therefore, contracts down to 39°·5, or, according to some, 39°·34, at which temperature it has attained its greatest density and contracts no more, but sinks to the bottom if the water beneath it be less cold. Hence in deep lakes the bottom is invariably at the temperature of 39°·5. In summer the temperature of such lakes decreases downwards ; in winter it increases in the same direction, and no ice can be formed on it till all the water in the lake shall have been reduced to the temperature of greatest density. Very deep lakes, therefore, may remain unfrozen, and water at the temperature of 39°·5 may flow from a lake frozen at its surface.

Such is the process of congelation in fresh water ; in the sea it is more complicated, for salt water in congealing expels the salt, which offers a certain amount of resistance to the act of congelation ; the freezing-point, therefore, varies with the degree of saturation, and in the case of sea-water is about 28°·5. The ice of sea-water, if quite clean and free from brine on its surface or in its cavities, is perfectly fresh and purer than most of the water found in the natural state on land. By melting sea-ice and recongealing it two or three times, an easy process in high latitudes, it may be completely freed from salt. Salt water does not dilate as its temperature sinks to the freezing-point, but continues to contract below that point more or less according to its degree of saturation, so that its temperature at its greatest density in the fluid state cannot be easily determined. Its congelation, like that of fresh water, is attended with a sudden and very powerful expansion.

The greatest thickness attainable by ice, or the depth to which frost can penetrate in the sea, does not seem to be perfectly ascertained. 20 feet is stated by Pouillet to be the greatest known thickness of ice; but Scoresby and Dr. Kane, both well acquainted with the ice of the arctic regions, allow it a thickness of only 10 feet. We may be assured that ice 20 feet in thickness cannot be the production of a winter's cold on the surface of water, but may be the result of sheets of ice thrown one upon another, or it might be to some extent glacier-ice formed by the accumulation of snow on sheet-ice. We are told of ice-cliffs 300 or more feet high, and extending for hundreds of miles. If they do not conceal land, of which there is often no symptom, how could they have originated unless by the heaping of ages of snow on ice? Thus they are to be regarded as sea-borne glaciers, perpetually wasted beneath and restored from above.

The sea must have fallen to the temperature of 26° or 27° before its congelation commences. The thin irregular flakes first formed on it are by the sailor called "sludge." When compact enough to hold snow, they are named "brash." Gathered into roundish masses they become pancake-ice; then come floes and hummocks, or protuberant masses of various sizes. Field-ice may have great extent; pack-ice presents a group of various character; and finally the iceberg, or mountain of ice, is most formidable in appearance. But the greatest danger to be apprehended by the seaman is that of being surrounded by heavy field- or pack-ice, when, if his ship escapes being crushed, it may drift with the ice a thousand miles from its destination. The risk of collision with icebergs is very serious; but they are dangerous even at a distance. Seven eighths, at least, of the whole mass is under water, and is constantly washed by the salt water which attacks the ice; consequently by loss of substance the centre of gravity of icebergs changes place, and they often tumble over, causing great disturbance in the sea around. Icebergs may be met with covering an area of some square miles, and with a height of 300 or 400, or even, in the south polar seas, of 1000 feet; and in the lower latitudes of their occurrence nothing is more remarkable than the excessive cold that proceeds from them. It is said that at the distance of 7 miles they depress the temperature of the sea 10° or 15°. This can be explained only by the chemical action of the salt water on the ice. Above, where melted by the sun, the iceberg has only the ordinary temperature of ice; below, where the salt attacks it without heat, it may be 20° lower. European meteorologists have not yet discovered the cause of the sudden fall of temperature that frequently occurs in the second week of May. Is not this about the time of the maximum discharge of ice from the Polar Sea, and passage of icebergs through the Northern Atlantic Ocean?

In the northern hemisphere Greenland is the great nursery of icebergs. Of the land round the south pole, which is doubtless quite as prolific of ice, we know little. Greenland, with an area of perhaps a million square miles, is an island or group of islands completely covered or bound together by ice and snow. Its mountains, so far as known, have a height of 6000 feet; its valleys are all filled with glaciers, or the compressed snow of ages. These glaciers, resembling frozen rivers, move down slowly to the sea; they may advance into it two or three miles; but ice being lighter than water, and glacier-ice the lightest of all, the surging sea, often trying to lift it, at length breaks it off, and the iceberg is launched, or, in seamen's language, it is calved. From Greenland alone probably not fewer than 400 great icebergs annually descend into the Atlantic; but here, it must be confessed, statistical details are failing.

The limits of the winter ice round the north pole may be thus sketched. From the southern extremity of Greenland the ice extends without interruption along its eastern coast and to the island of Jan Mayen; then cutting the meridian of Greenwich in about lat. 71°, and running N.E. for 150 or 200 miles, it runs northwards and leaves clear the sea known as Whale Bay, extending up to lat. 77° N., and in summer to lat. 80°. At times ships can go up along the western coast of Spitzbergen, and even reach the most northern point of that land. From the south-eastern end of Spitzbergen the ice strikes off to Novaya Zemlya and the coasts of Siberia. These coasts are encumbered with ice at all seasons ; open sea, or, as the Russians call it, a polinya, may indeed be seen beyond the ice, but nothing is known of its extent. North of the American continent ice is abundant ; and though there are some open channels between the islands, their freedom from ice is not assured but merely accidental. In short it may be stated without any material error that the domain of ice is bounded in the northern hemisphere by the 75th parallel of latitude ; for though open water may be found north of that line on the side of Iceland and the Atlantic, ice extends much further south of it on the side of Behring's Straits. When it was announced by Brewster that there were in the north two poles of cold (one in Siberia, and the other a little north of the American continent), it was assumed that between those poles, or at the north pole of the globe, might be found a temperate climate ; but this delusion has been dispelled by the careful investigations of Dove, who concludes that there can be little remission of rigour in any part of the elliptical tract which connects across the pole the points of lowest temperature.

The southern pole is still more unapproachable. Sir James Ross was singularly fortunate in being able to reach the latitude of 78° S. There he saw a barrier of ice apparently immovable ; but in general, in the southern ocean, even in summer, it is dangerous to advance through the ice beyond the 70th parallel. As to the winter limits of the southern ice nothing is known.

Icebergs sometimes run aground on the banks of Newfoundland in 120 or 130 fathoms, and frequently descend to lat. 42°. Occasionally they go much further, and, driven about by wind and currents, wrecks of great icebergs have been seen in the warm sea near Havana (lat. 24° N.). Icebergs from the south have been met with as low down as 35° lat. in the Indian Ocean. They sometimes reach the mouth of the La Plata (lat. 37° S.). Icebergs, while drifting with the current, often spin round, sometimes rapidly, when so shaped that one half catches the wind more than the other.

When the atmosphere sinks to a temperature below the freezing-point, the humidity contained in it, being congealed, can be precipitated only in the form of snow, sleet, or hail. It is probable that in high latitudes much that leaves the clouds as snow melts in descending, and reaches the ground as rain. Snow exhibits in a great variety of forms (above a thousand have been observed) the characteristic crystallization of ice, the elementary particles of which seem to be hexagonal, uniting at angles of 60° or 120° (fig. 99). The ramifications visible in snow, however varying in other respects, are constant in these angles. Scoresby has reduced all the forms of snow to five classes :—1, thin plates, the most beautiful and multiform class ; 2, a central nucleus studded with spicules ; 3, the six-sided (very rarely three-sided) prism ; 4, six-sided pyramids ; 5, a prism with plates perpendicular to it at equal distances. The regularity of snow-crystals seems to attest their perfect freedom from disturbance during the process of congelation. Their lightness and delicacy increases with the elevation from which they descend. But it is impossible to imagine the modifications of temperature, pressure, and cohesive and electric attractions which bring about such a wonderful variety of symmetrical figures. We know not whether the different forms of snow fall separately, or whether at one time and place several may fall together. The statement that after a heavy fall of snow different kinds of trees have been found to be covered with different forms of ice-crystals, seems hardly credible. Of fine snow 22, or even 24, volumes are required to give one of water. The density of water to that of snow is generally assumed on the continent to be as 14 to 1. This estimate may perhaps be founded in some degree on experiments made with snow from the High Alps. English meteorologists

Fig. 99.

assume that water is to snow in density as 10 to 1. The red an green snow occasionally met with are ordinary snow coloured b a minute organism (*Protococcus*) like the pollen of a flower.

It is impossible to fix with precision the geographical limit within which, at the level of the sea, snow may occasionally fall Snow is very seldom seen at Gibraltar or on the southern coast of Spain. In Southern Italy, at the level of the sea, it is les rare, and has fallen heavily at times at Naples and Palermo. I Greece it seldom reaches the plains, but covers the mountains a the height of 6000 feet. Further eastward the snow-line bend to the north, owing to the increasing dryness of the climate ; ye occasionally storms from the north bury in deep snow the warn plains of Southern Europe. In January 1850 they even reache Africa ; snow fell heavily at Ghadames and Sokna, far withi the desert south of Tripoli. The flat roofs of the houses fell i from its weight, and ice an inch thick was formed at Morzuk, i lat. 26° N., in the land of the date-palm. Thus it appears tha though snow is extremely rare so far south as the 30th parallel which is generally assigned as its limit in Europe, it yet may g far beyond it. On the Northern Atlantic Ocean the limit recede to lat. 45° N. ; in the United States it is fixed at about the 33r parallel. On the western side of North America, owing to th extreme dryness of the climate, it is found at the 47th, and o the shores of the Pacific at the 40th parallel.

Snow lying in loose heaps, confining a great quantity of air is a very bad conductor of heat, and consequently protects fron frost the ground it covers. Farmers are justified in their dislik of black (*i. e.* snowless) frosts. A covering of snow prevents th penetration of frost from without and the radiation of terrestria heat from within, so that there may be a difference of 40° between the temperature of the ground and that of the surface o the snow above it. On temperature alone it depends whethe snow may fall ; but its abundance requires the union of low temperature with humid skies. Of this union there seem to be fev examples in the northern hemisphere. In Northern Siberia th snow is rarely deep ; the reindeer can always find moss on th tundras, and every burán or snow-storm lifts all the snow fron the ground, and leaves bare new feeding-grounds, while it cover up the old ones. In the southern hemisphere it is almost perpetual in latitudes corresponding to those of central Scotland ; and on the western side of South America, south of Chiloe, it falls in immense quantities, evidently not owing to the rigour of the climate, but to the fact that, even at freezing-point, the air is always loaded with humidity.

In all latitudes snow may fall at great elevations. Perpetual snow is the name given to the frozen covering of mountains, which, rising above the level of congelation, receive from time to time snow enough to make good the waste occasioned by evaporation. Thus the snowy covering is perpetual, while the snow itself is evanescent. Nor is there any reason for believing that the accumulations of snow formed above the line of congelation go on continually increasing or are ever very considerable. Limits are set to their growth by the increasing dryness of the atmosphere higher up, attended by greater loss from evaporation with a less supply of snow. Indeed it may be suspected that the snow-like covering of the highest summits (as, for example, that of Mount Everest in the Himâlaya) is supplied chiefly by the frozen evaporation of the snow-fields lower down.

It is not easy to determine with precision the limits of altitude within which snow may fall in tropical countries. In equinoctial America Humboldt never saw it fall at an elevation less than 11,000 feet. In Mexico, in lat. 19° N., heavy showers of snow are not unusual at the height of 7000 feet. In Bolivia, on the other hand, at the same distance southwards from the equator, it rarely occurs below the height of 12,000 feet. The limit of perpetual snow, however, or the line above which snow is always to be found, though depending on several conditions variously combined and regulated by no simple law, is much better known. The following Table of observed heights of the snow-line will sufficiently illustrate its modified regularity.

		Lat.	Altitude of perpetual snow above sea.
		° ′	feet.
S.W. point of Spitzbergen		78 N.	0
North Greenland		75	2345
Bear Island		74 30	500
Mageroe	Finmark	70 30	2342
Qualoe			2664
Seyland			2906
Talvig			3477

		Lat. °	′	Altitude of perpetual snow above sea. feet.
Sulitelma, Lapland		67	N.	3835
Iceland, Osteryökul		65		3070
Mountains of Lodals	Norway	61		5429
Between Lyster and Yastedal				5329
At Urland Fiord				5183
Fillefield				5577
Folge fonden fyeld				5249
Northern Ural		59	30	4790
Shevelutch, Kamchatka		$56\frac{1}{2}$		5249
Unalashka		53	30	3510
Altai		50		7034
Eisthaleropitz, Carpathians		49		8604
Alps		46		8884
Elbruz	Caucasus	43		11,063
Kasbek				10,613
Pyrenees		42	45	8950
Rocky Mountains		43		12,467
Apennines, Gran Sasso		42	30	9521
Ararat		40		14,166
Argæus, Asia Minor		38	30	10,702
Bolor		37	30	17,011
Etna		37	30	9530
Sierra Nevada, Spain		37		11,187
Toluca	Mexico	19		14,675
Nevado Iztaccihuatl				14,737
Popocatepetl				14,970
Abessinian Mountains		13		14,061
Sierra Nevada de Merida		8		14,928
Tolima		5		15,312
Purace		2	30	15,308
Nevados, near Quito		0		15,825
Andes		1	S.	15,794
Guaracolta	Eastern Cordillera of Bolivia	14	30	16,243
Illimani		16	45	15,610
Inchocayo	Western Cordillera of Bolivia	16		16,840
Arequipa		16		17,716
Chipecani		17	45	18,346
Sajama		18		19,439
Paachata		18		20,079
Portillo	Chili	33		14,708
Coast Cordillera		42	30	6010
Straits of Magelhaens		53	30	3607
Hindu Khush		34	30	12,979
Himâlaya	Northern slope	30	30	16,624
	Southern slope			12,979
Karakorum, Southern Tibet		....		19,400
„ Northern Tibet, Turkistan		....		18,600
Gauri Sankar, Western Tibet		23	5 N.	
„ snow-limit, Western slopes		....		18,665
„ „ Northern slopes		....		18,010
Laóche pass		34	14	
„ Northern slopes		....		16,400
„ Southern slopes		....		17,900

From this it will be seen that about the equator, or a little to the north of the equinoctial line in America, the snow-line remains uniform for some degrees, and sinks slowly towards the north. In the southern hemisphere, on the other hand, and especially in the Eastern Cordillera of Bolivia, it rises considerably, in consequence, not of increased temperature, but of deficient humidity. The line of perpetual snow is raised by high temperature, but at the same time is liable to be lowered by the abundant vapours and precipitation that accompany heat. Its height, therefore, depends not more on temperature than on the dryness of the air; and by the combination of these two conditions its position is determined. Hence in the Himâlaya the snow-line rises towards the west and north, and is highest on the northern side of the mountains, because in those directions humidity decreases. For the same reason it rises in the Peruvian Andes as it recedes from the equator, on the western or leeward Cordillera. Again, the snow-line is higher in Kamchatka than in Unalashka, on the north-western coast of America, where the climate is much milder; but humidity and therefore snow are abundant at the latter place, while they are scanty in Kamchatka. In like manner Bear Island, with a less rigorous winter than North Greenland in Baffin's Bay, has nevertheless a more copious supply of snow than the latter, and therefore a lower snow-line. The comparative lowness of the snow-line in Southern Chili and hence to Magellan's Straits, near which, in lat. 45° S., it falls nearly to the level of the sea, is to be ascribed not so much to low temperature as to the almost incessant precipitation of snow. And here it may be remarked that the line of perpetual snow, though frequently called the line of congelation, is different from, and always higher than, the latter; for though snow when fresh may be taken to mark a certain temperature, yet it is wasted by evaporation at all temperatures; so that the true line of perpetual snow lies somewhat above the line of congelation and at a temperature below the freezing-point, the difference varying from 2°·5 Fahr. to 12° according to the latitude and exposure to drying winds. In the Alps the temperature of the snow-line in summer is about 25° Fahr., in Norway 24°.

Water when frozen loses its valuable properties as a moderator of temperature; ice may become intensely cold, and it greatly impedes the return of heat. The great difference which exists between the climates of Siberia and of North America is traceable to the circumstance that the latter country has proportionally a much greater length of ice-bound coast, more effectually cut off from the great ocean, and also a much greater expanse of lakes. These waters somewhat retard the advance of winter cold; that is of little value; but when spring returns, the temperature of the air cannot rise till the ice is all melted. An enormous quantity of heat must be consumed to restore fluidity to the lakes and adjacent seas; and till that is completely done winter still remains. Hence Siberia has the advantage of an early spring; it feels severer cold and also greater summer heat; but in the speed with which it gets rid of winter and enters on the enjoyment of a long spring it has a great advantage.

It is evident that wherever congelation is perpetual, as in the frozen ground of Siberia and North America, ice may be regarded as a rock, which differs from other rocks chiefly in melting at a much lower temperature. In such climates, houses, good for nine months of the year, may be easily built of snow, converted into ice by pressure. A remarkable proof of the applicability of ice to such purposes was exhibited in the ice-palace built at St. Petersburg in 1740, by command of the Empress Anna. It was 53 feet long, 17 wide, and 20 high, roofed with ice. In front of it were planted six pieces of cannon, 6-pounders, all of ice, turned in the lathe, and from which balls of oakum were fired without bursting them. Snow huts are the ordinary habitations of the northern tribes in America and Asia. With fresh snow heaped round them they are comparatively warm, afford good shelter, though under one uncomfortable condition—namely, that no fires be lighted in them.

The existence of what is called ground-ice was long doubted; but careful observation has established the fact that at the bottom of rivers, lakes, or other shallow waters ice is often formed before it begins to appear at the surface. It may be presumed in these cases that the ground is colder than the water; but the circumstance that seems to give to the bottom of the river the priority in congelation is, that there, under the edge of stones, and averted from the current, may be found at once the vibration and the perfect shelter required for the formation of the first crystals. The ground-ice thus formed grows in vertical flakes, grouped together so as to resemble some kinds of sponge. It often breaks off and floats on the surface, where it promotes congelation. In harbours on the shores of the Baltic Sea large stones, ropes, iron chains, and even anchors have occasionally been raised to the surface by the luxuriant growth of the ground-ice attached to them.

The freezing of rivers and lakes generally begins at the sides, the first crystals being formed at the sheltering edge of some stone, and the ice spreading thence in horizontal flakes of a thickness depending on the temperature. But if the cold increases the ice thereby added underneath it is formed in crystals perpendicular to the ice that already covers the surface. Wherever, therefore, the ice continues through the whole winter, the upper or horizontal and, it may be added, the binding stratum is sooner or later worn or wasted away, leaving behind it the secondary growth of totally different structure and breaking easily in a vertical direction. Hence on the Neva and other such rivers a dangerous condition of the ice, when a cane may be easily thrust through it, precedes for some time its breaking up.

To the animal creation, polar bears excepted, which live not so much on the land as on the ice, congelation seems to be an unmitigated calamity. The fishermen of the river Obi say that immense quantities of fine fish die under the ice of that great river, poisoned they believe by mephitic vapours. In truth, the ice, while it excludes fresh air and oxygen, prevents the escape of the carbonic acid gas generated beneath it. The streams on the eastern side of Siberia, which fall into the sea of Okhotsk, have generally a rapid course, so that they are completely discharged and dry before the winter ends. When the ice, therefore, that covers them breaks and falls in, it discloses nearly empty river-beds with dead fish lying in heaps for hundreds of miles. M. Erman, describing his journey down the course of the Okhota, relates as follows :—"In all the flatter parts of the valley, where the river was more shallow, there was an insupportable smell of fish in a state of putrefaction ; and on every side large salmon were to be seen just exposed to view by the melting of the snow. On the gravel banks at the waterside they were strewed as thick as possible, and on the islands, which are overflowed in summer, they lay in heaps one upon the other. . . . . The drivers (of the dog-sledges) took from this inexhaustible store some of the better preserved fish, 2 feet or more in length, to throw to the dogs at night." These fish were nearly all salmon of two varieties, viz. the *Salmo lagocephalus* (hare-headed) and *S. collaris* (or malma).

In the Altai Mountains deer perish in multitudes as often as their egress from the sequestered valleys is prevented by deep snow fallen in the mountain-passes. It is related by the missionary M. Huc that, on his journey from China to Tibet, he descried a great river in a wide valley, and what appeared to him to be a numerous army encamped on its banks; but on approaching nearer the supposed army proved to be composed of myriads of wild cattle intent on crossing the river. The leaders of the herds, however, were impeded by the new ice just forming and gathering before them, and could not get through. Behind them the other cattle hurried into the stream and crowded together, unable to advance. In the mean time congelation went on rapidly; and when M. Huc reached the river, the cattle were all firmly clasped by strong ice, and over them swept a dark cloud of birds of prey plucking their eyes out.

CHAPTER XXII.

Mountains—their Importance—Impressions made by them.—View from the Summit of the Alps.—High Snow.—The Chasm.—The Firn or Névé.—Depth of Snow.—Glaciers—Conditions of their Formation—Primary and Secondary.—Moraines.—Guffer-lines.—Seracs.—Tables and Veined Structure.—Dirt-bands.—Number and Size of Glaciers—their Movements—Variation.—The Œtzthal group of Mountains.

Inconsiderable as the protuberances of the earth may appear in relation to its general figure, their significance becomes manifest as soon as they are compared with the height of the atmosphere ; for mountains often rise above the level of the clouds, and far above that portion of the atmosphere in which the chief meteorological phenomena, or those most directly affecting the inhabitants of the earth, take place. It is necessary, therefore, to give attention not only to the distribution of the land, but also to its elevation ; for land has the peculiarity of being far more susceptible of extreme temperatures than the sea, and it may also rise to such a height as to interfere with or completely divert from their course the denser currents of the atmosphere.

Few men are insensible to the charm of mountain-scenery. Mountains banish monotony from the earth's surface. Their outlines, graceful or fantastic, vividly traced on the sky and their many tints mellowed by distance, holding out the promise of bright light and wide prospect, engage the imagination. The individuality of their forms makes a deep impression on the memory ; so that of all men mountaineers are most characterized by local attachment. They never forget nor lose their affection for the well-marked features of their early homes.

The influence of mountains, however, on human feelings depends but little on their absolute magnitude. The eye is best satisfied with what it can well embrace, and most frequently finds beauty where there is nothing colossal. It is most gratified with mountain-scenery on a scale not so great as to preclude the possibility of surveying its whole grandeur at once. But the physical influence of mountains, which is here the proper subject of consideration, bears in general some proportion to their altitude and extent. It cannot be experimentally studied without toil and patience. The natural phenomena of hill and valley must be investigated from the base of the mountain, over rocks and glaciers to the highest point attainable above the limits of perpetual snow. In this ascent the hardy traveller has probably to pass through all the gradations of climate experienced between the equator and the poles. But the fruits of all this labour may also be easily learned in an agreeable manner by combining the results arrived at by trustworthy observers ; and since the Alps, rising above the limits of perpetual snow and presenting all the essential characters of mountain nature, are also the mountains best known to us, a review of the physical phenomena observable on them from base to summit will furnish a text which, occasionally modified and completed by reference to other elevated ranges, will sufficiently reveal the physical importance of mountains in general.

The Alps have, in respect to their scenery, this great advantage, that the cultivated valley and the snow-clad mountain there lie often side by side and may be seen close together. The amenity of the one and the stern grandeur of the other are thus rendered more striking by contrast. In the valleys at the feet of the Alps, at absolute elevations of from 1500 to 3000 feet, we see towns or villages picturesquely seated on the banks of lakes or of rivers, fed by lively streams from the surrounding heights. Corn-fields, gardens, vineyards, spread or clustered round them, occupy every hollow in the hill-sides. Above these, to a height of 8000 feet or more, hang woods of chestnut, oak, beech, and fir. Where the pine-trees cease, begin the elevated summer pastures, which, in the language of the Swiss peasant, are properly styled "the Alps." But high above these again rise the realms of snow, with numerous peaks and crests far above the ordinary level of the clouds. Such is the summer aspect of Switzerland,—tranquil beauty in the foreground—and, around a varied grandeur always impressive, often gloomy and austere. In winter hill and vale are alike covered with snow, and all take for a time the character of the highlands.

The region called the High Alps, which is perpetually wrapt in snow, has an extent of 1484 square miles, and presents everywhere a spectacle at once singular and sublime—a boundless solitude with bare dark rocks projecting here and there from the general white surface, while snow-covered crests and ridges rise confusedly like the waves of a stormy sea. The clouds are seen floating below ; the clear sky overhead has taken a deep blue colour, while the neighbouring earth seems wrapped in a pure white shroud. The peaks and rocks on a level with the eye appear wonderfully distinct, every line and spot on them being visible at a great distance. And yet the prospect, instead of being enlarged, has become remarkably circumscribed, the aerial obscurity increasing much more than the width of the horizon. To one looking up from the valley, the mountain-peaks, the most distinct points in the prospect, are also the most distinctly marked and most attractive. But from the elevated summit, on the other hand, the valley seems overshadowed and is dimly visible. The more dense and humid atmosphere below hangs like a mist, screening from observation all beneath it, while it reflects the glare of the sunbeams. The snowy waste is less monotonous than might be expected. The grand scenery around, as well as the difficulties and dangers of the path across it, changes at every step. The traveller perceives that the aspect of the snow at his feet continually alters as he ascends or descends. But the transformations of snow between the summit and the base of the mountain deserve to be attentively studied.

Let us suppose, then, that we have reached one of the highest summits in the Alps, that of Mont Blanc, 15,744 feet, or of Monte Rosa, 15,151 feet high. At such a height snow falls rarely, rain probably never. At an altitude exceeding 11,000 feet snow ceases on the Alps to fall in flakes, and appears only in the form of spicules or needles and in small stars, which grow lighter and more minute the higher we ascend. But though the highest summits of the Alps are little subject to precipitation of rain or snow, the clouds occasionally rise above them ; and doubtless the points thus wrapped in a saturated atmosphere attract and retain a portion of the congealed humidity, deposited probably in a form resembling that of hoar-frost. It may be conjectured that all peaks rising far above the ordinary height of the clouds owe their snow-like covering chiefly to the evaporation from the snow-fields below them, the vapour being carried up by the daily ascending currents, and there, after the quick transit of noontide heat, congealed about the summit. Hence it may be doubted whether the frozen covering of the highest points be not thicker in summer than in winter.

This fine snow is extremely dry and easily breaks into snow-dust which fills every crevice. It is dry, not because it remains unaffected by the sun's rays, but because evaporation in the rarefied atmosphere is so active as to remove instantaneously all aqueous vapour. This extremely fine and dry snow near the summit is distinguished by its dazzling whiteness, due partly to its minuteness and dryness, and partly to the intensity of light in the attenuated atmosphere at great altitudes. Green glasses or wire gauze to defend the eyes become necessary at the height of 10,500 feet. At 10,000 feet the want of them is hardly felt.

The fine snow about the summit generally forms a hard even crust without furrow or irregularity; but at the base of the crest, where the valley begins to open, there occurs not unfrequently a deep gap or rent in the snow, called by the mountaineers "Bergschrunde" (mountain-chasm). This line of weak adhesion seems to separate the region of dry snow-dust on the one hand from the extensive fields of deep snow on the other. It was in a crack or chasm of this sort that M. Hugi, when ascending Monte Rosa in 1829, spent the night, at an elevation of 10,358 feet. It was 60 feet deep and 60 wide at the top, but narrowing downwards to 30 feet, and at one end led into ice-caves of apparently immeasurable extent. Beneath the dry snow there is no ice. Near bare projecting rocks, the radiation from which, when they are heated by the sun, melts the snow around them, pools of water are often formed and soon after congealed into transparent ice. But this, near the summit of the mountain, is a comparatively rare phenomenon. Lower down, where there is more humidity, the water makes its way through the snow, and forms beneath it a layer of ice, which grows thicker as the elevation diminishes. In the snow that covers that ice cracks or crevices are frequent, most of them only a few feet wide, so that they may be leaped over or else bridged with a plank; but occasionally they are found with a width of 40 or even 100 feet. They originate for the most part in the underlying ice, being caused by rocks or changes in the configuration of the ground over which the whole mass moves. Over convex ground their walls diverge upwards. When the ground is concave or sinks into a hollow, the crevices converge towards the surface, being narrow at top and wide at bottom; these latter are deemed the most dangerous, being often concealed by fresh snow unable to support the incautious traveller, who thus falls through it into the abyss.

As we descend, the snow gradually loses its pure, dazzling whiteness, growing bluish and stained by the dust carried up by the wind. It also assumes a granular texture, the grain when divided showing an icy kernel and a snowy rind, as if it were the produce of a snow-star collapsed into a globule, and then frozen and increased by the congelation of the ambient vapour. The granular structure grows continually coarser lower down. At the height of about 9000 feet the grains have the size of hemp-seed, and the "Firn" (as the Swiss call the granular snow) softens a little by day, and is at night frozen into clusters. The transformation of snow into firn seems to require a year, the increase of the grains in descending being due to the increasing abundance of aqueous vapour condensed on their surface. Thus it appears that in the whole snow-field of the High Alps, from their summits down to the glaciers, we may distinguish three zones, viz. the high snow, the firn (in the French cantons called névé), and the lower snow. By some the firn is divided into two or three zones; but the truth is that the change from minute and dry snow to firn and then to snow-flakes takes place gradually, so that with continual change of character there is no well-marked line of separation. The lower snow occupies a narrow zone, corresponding to about 50 feet of vertical height, between the firn and the lowest snow-limits.

Snow falls most abundantly at the level of the clouds, or between the altitudes (in the Alps) of 6000 and 9000 feet. Its greatest accumulation is at the latter height. The average annual fall, varying much in different situations, may be assumed to be about 40 feet, which shrinks in a short time to 15 feet. The daily and separate falls may be about 2 or 3 feet, quickly reduced to from 10 to 3 inches. Snow is wasted, even at a low temperature of the air, not merely by evaporation, but also by the heat arising from the pressure of its weight and of the wind, which melts it in the part most compressed and whither the fluid tends—that is, at the bottom. The water thus mixed in small proportion with deep snow, soon congeals; and it is obvious that the ice underlying the névé or snow-field must continually increase in thickness towards the lower limits of the latter. Deep crevices in the snow often lay bare its icy foundations. Crevices have been sounded to a depth of 200 feet. One instance is recorded of an ascertained accumulation of snow and ice to a depth of 700 feet; and well-founded conjecture assigns 1500 feet as the vertical measure of the congealed mass which fills up certain great valleys. The snow on the summit of Monte Rosa is supposed to have a depth of 10 feet, increasing downwards to 18 or 20 at 10,500 feet. There is probably no ice beneath the snow on the Alpine summits; but below the altitude of 11,000 feet the icy foundation increases rapidly and approaches nearer the surface, till at the lower limit of the firn it comes forth as a glacier.

The frozen covering of the High Alps, though apparently strong and able to bear the tread of the traveller or hunter, yet possesses but a qualified solidity. At its lower limit alone it is sure to meet with the temperature that melts it; but it is everywhere liable to be temporarily relaxed by the heat of compression or of the solar rays. It undergoes incessant metamorphosis, generally implying loss of volume. The snow changes into granular firn, the firn into ice, which contracts with increasing cold, though, by the congelation of water trickling through it, the whole mass may be forced to expand. The surface of the snow-field is riven by cracks or crevices, most numerous where the declivity is steep, the ground uneven, and the underlying ice thick. Their continual change, closing and reopening, shows how the mass is affected by and yields to pressure. The consequence is that the snow or ice moves downward unceasingly, its motion resembling, in all but its slowness, that of a river. It was justly observed of glacier-ice by Mr. E. Forbes, that it seems to unite the rigidity of a solid to the flexibility of a fluid. Snow compressed becomes ice ; ice is fragile, but when broken to pieces it easily (if moist) reunites again, its temperature being still that of congelation. Thus the semblance of fluid nature observable in ice is due to its fragility ; for it evades resistance by breaking to pieces, and flows down the declivity, not uniformly and in atoms, but fitfully and in fragments. Then, again, left to uniform pressure, it reunites and consolidates.

The indispensable conditions of a glacier, or of a constant stream of ice below the limits of constant congelation, are :—1st, accumulation of snow, which cannot be melted and carried off in a fluid state at the height where it falls. Such accumulation can take place only where the summer is short, the winter long, and the precipitation copious. It is necessary also that the water be retained, which rarely happens on limestone. 2ndly, a moderate declivity of the snow-fields, so that they may not be exhausted by a too rapid discharge ; and, 3rdly, the snow-basin, or reservoir must be hemmed in by ridges, so as to confine the efflux to a comparatively narrow channel. Through this it must descend to a warmer region in the same manner as a river ; and if the reservoir or snow-fields above be sufficiently ample, so that the accumulations of winter fully equal the waste of summer, the glacier may remain nearly constant. The spacious basins which serve as reservoirs for the snow occur most frequently in mountains of granitic or crystalline formation, such as predominate in the Swiss Alps. In limestone-mountains the hollows are generally narrow, the summits extensive plains, the rock cracked throughout so as to drain the surface, and the slopes precipitous. Volcanic cones, such as those which in the Andes so frequently rise above the limits of snow, are too steep to retain the snow long, and too uniform in shape to impede its descent in any direction, so that it spreads rapidly and widely below the line of congelation, and disappears without forming a glacier.

The stream of ice which, occupying a main valley, connects the snows of the summit with the fertile plains is called a primary glacier ; it receives in its course many tributaries, or ice-streams, from lateral valleys. These secondary glaciers, as they are called, differ from the primary, not only by inferior length and magnitude, but also, in general, by greater steepness and abrupt irregularity ; they are the torrents, as it were, which feed th ice-river. Many of them do not reach so far down as to mee their primary ; but their ice accumulates at certain points ti it breaks off, and falls with the noise of thunder, and in a thousan fragments, on the glacier below.

As the ice descends, pressed on by the weight of the constantly increasing mass in the rear, it has to encounter the friction of the ground and of the rocks on both sides. It move faster, therefore, where least hindered—that is to say, at the to and in the middle. Consequently the glacier, viewed in its transverse section, is convex or highest in the middle of the stream and all the undulations marking its surface are most prominer on the line of that convexity and point down the stream. Bu the line of greatest convexity is not strictly and constantly in th middle of the stream. As a rapid river, rebounding from one c its banks, rushes on till it strikes the other and never confine its strength exactly to the middle line between them, so th glacier at every turn of its bed shows itself slow to change it direction ; and the line of its greatest convexity always leans t the lower end of the concave side at every turning of the bec Stones and even rocks of large size lie strewed over it, torn awa from the sides of the valley by the pressure of the ice ; whil many also have fallen from peaks and ridges at great heights where the rocks are split by the congelation of the water whic has penetrated their fissures.

As the exposed ice rapidly wears away, while the glacier, fe from above, still maintains its height undiminished, stones whic have sunk in it, or fallen into hollows, sooner or later come t the surface, the convexity of which and the constant change c substance again throws them to the side, where, for obviou reasons, loose stones are, in the first instance, most numerous The Swiss peasants believe that the glaciers have the power c purifying themselves by expelling all foreign (*i. e.* all unmelting bodies ; but this apparent power is merely the consequence c the general wasting of the mass, while the pressure from behinc keeping it at a nearly constant height, conceals its diminutior Every glacier at its first formation drives down a mound c stones, which is subsequently increased by all that descend to it ermination in the course of ages (see the Frontispiece). These ccumulations of stones are called *Moraines*, that in front of the lacier being the *terminal* moraine, those on its sides the *lateral* moraines, or guffer-lines ("guffer" means rubble). But as nearly very glacier has its own moraines, those of the secondary glaciers re carried down to the primary and mark on the body of the nited stream the boundaries of its component members. Thus he great glacier has ordinarily as many guffer-lines as tributa- ies; and these, coming from different quarters, are often formed f totally different kinds of rock, distinguishable at a distance y their shape and colour; but they are all thrown together in he terminal moraine. There the mineralogist may find specimens from all the rocky crests within the basin of the glacier, nd may point out the locality from which each has descended.

Moraines vary much in character and magnitude. A few laciers have guffer-lines of gravel, or even none at all; while the most numerous class that force their passage down rocky slopes erminate in huge piles 50 or 100 feet high, and formed to some xtent of rocks of great size. They look like rude walls raised y some giant power. When the glacier, after a series of very warm or dry years, happens to retreat, stones are strewed by it ver the deserted ground, as the commencement of a new moraine in the rear of that abandoned; but if it again advances, hese new deposits are all pushed forward and added to the old ne. Throughout the valleys of Switzerland there remains everywhere proofs that in former ages the glaciers advanced far eyond their present limits. Moraines of immense size with cratched and abraded rocks mark their ancient course, and show hat the action and influence of the glaciers once reached 2000 or ven 3000 feet above the level of the valleys now at their feet.

Wherever the slope is moderate and the valley uniform and lirect, there the glacier presents a tolerably smooth surface, free rom cracks and abrupt ridges; but with steepness increases he disruption and disorder of the ice, the number of cracks and leep chasms. Glacier-ice cannot pass down a declivity of more han 30° without being completely shattered. Its fragments are hen thrown into the wildest confusion—pillars, pyramids, and towers of ice figure the ruins of some great city. Such monuments of violence and confusion on the glaciers are calle "seracs." If water flow anywhere on the surface of the ice i soon wears itself a channel, and gathers strength as it runs, til at last it falls into some gap in the ice, through which it work its way to the bottom. Thus the stream flows off, forming wha is called "a mill."

Stones, it has been stated, often fall from the hill-sides on th ice. Heated by the sun's rays, they melt the ice round them and after a short time are seen to stand each in the norther focus of a hollow ellipse, formed by the radiated heat of the stone They may sink for a time, but as the ice wastes they come agai to the surface. A flat stone, however, is more likely to protec than to melt the ice about it. Hence *Tables*, as they are called or stones each supported by a pillar of ice, are frequent on th glaciers. In general, stones or dirt scattered on the ice tend t melt it; but when they lie together so as to make a compac covering they screen and protect it.

Among the characteristics of glacier-ice there is nothing mor singular and striking than the veined structure so often conspicuous on its surface. Its origin is not obvious; and the attemp to explain it has called forth to little purpose very divers opinions. Mr. Forbes was undoubtedly in error when he stated his belief that "the veined structure is not original"—that is t say, that it is not to be found in the ice at the origin of glaciers but "owes its existence at any moment to the conditions o varying velocity." Yet the dirt-bands, which are intimatel connected with the veins, he was disposed to regard as "th true annual rings of the glacier." Others ascribe the veins t "ice-cascades;" but how regularity of structure can originat in disorderly fragments it is hard to understand. The mos accepted doctrine is, that the structure in question is the resul of compression, and may be compared to the slaty structure i rocks, which is supposed to be the result of a force compellin surfaces to slide one over the other in a certain direction. Bu this ingenious hypothesis appears to be totally inapplicable to th case of snow, the bands of which are certainly not formed by an sliding. The phenomenon is distinctly marked, and when closel examined is found to depend on internal changes, which, howeve originating, perfectly explain the appearance of the bands (see Frontispiece).

Throughout the snow-field horizontal stratification is generally observable, the strata or layers (from successive falls of snow) varying from three quarters of an inch to a foot in thickness, often separated by a thin line of dust, and more plainly marked at those altitudes where the intermissions of snowfall are longer. But it is impossible to trace any connexion between the horizontal layers of snow or firn and the veined or banded structure of the ice. We see the glaciers marked transversely with alternate blue and white bands, varying throughout in size and distinctness, but tolerably uniform in any one place and often very regular. Close inspection discovers that the blue bands are prominent, being composed of transparent ice, the cavities of which are filled with water. In the white bands it is easy to recognize the porous, opaque ice formed of compressed snow and filled with air-bubbles. This is the air disengaged from water in congelation, and unable to escape from the congealed mass. As air absorbs heat much more readily than water, the opaque ice melts under the sun's rays much faster than the humid and transparent ice. The latter, therefore, stands forth in ridges, and, taking the hue of the water that permeates them, appears, in contrast with the dry, opaque ice, decidedly blue.

Thus the veined appearance of the glacier is found to arise from the alternation in layers of dry and humid ice. The former, filled with air in its cavities and opaque, represents the original condition of glacier-ice. The air contained in them when heated enlarges its chambers, till they communicate with one another by capillary communications through the whole band, and become filled with the water of the melted ice. Coloured fluid poured on the blue ice descends at once to a great depth, and also spreads on the surface ; in the white ice it sinks slowly and only to a depth of 8 or 10 feet. In short the former is permeable throughout, the latter is not so. But what has produced this change in the ice at regular intervals? Those who ascribe it to compression are entitled to insist on the circumstance that the bands being transverse on the glacier are at right angles to the pressure. But, on the other hand, when they first appear at the head of the glacier, as yet unaffected by the impetus and accidents of the downward course, they stand in a vertical position. There has been no sliding to produce lamination in the mass ; and in the absence of lamination, why should the effects of pressure be exhibited at intervals, these intervals again varying widely in the same material? The bands stand vertically and in straight lines across the glacier at its origin ; but in descending they share in the general inflections of the ice, and thus assume new positions. As the middle of the glacier moves most rapidly, the bands, at first vertical, lean more forward as they descend, and change at the surface from a transverse straight line to a pointed arch. The width and regularity of the bands seem to depend on the constitution and velocity of the ice-stream at the place where they originate. Humidity is essential for the display of the blue bands. Early in the morning they are not seen ; an hour's sunshine renders them visible, and rain makes them vivid. They share in and render manifest all the disturbances of the ice ; and where this is thrown into disorder, the veined structure may be seen in every variety of position.

As the white bands yield more to heat they are more wor down, and form hollows between the blue ridges. The surface o the glacier presents the appearance of waves running into a dee bay, becoming more bent the further they advance, the ridge of the waves being blue, the furrows between them white. Thes furrows collect all the dust and dirt thrown on the glacier b stones falling from above or by winds from below. Thus th dirt-bands of the glacier are a consequence and accompanimen of the veined structure. The Ogives, again, or Gothic arches noted by some travellers, seem to be but another view of th same phenomenon. They are all that can be seen of the bande structure from a considerable height and distance, when loca and particular features have been lost sight of, and nothing ca be distinguished but the play of light and shade on the undulate surface.

In the Alps, from Savoy to the Tyrol inclusive, there are sai to be 60 primary glaciers and at least 1000 secondary. Of th former class the least has a length of three miles, while some, the Aletsch, on the south side of the Finsteraarhorn, extend to distance (the névé or firn-sea being included) of twelve miles. In width they vary from half a mile to a mile and a half. They are generally steepest at the termination, where they sometimes have a height of 500 feet above the valley. As to their depth, it does not admit of being estimated with any precision ; but it may, with some probability, be assumed to vary from 100 to 600 feet. The terminal moraines often attain a height of 100 feet, and form curved ridges with the concave side next the glacier. Many glaciers, particularly on the south side of the Alps, do not descend below 9000 feet, but in general they go down to about 5000 feet. The great Aletsch glacier descends 1000 feet lower, and that of the Grindelwald, the lowest of all, comes at the height of 3200 feet into the neighbourhood of corn-fields and gardens.

The movement of glaciers is regulated chiefly by the steepness of the ground beneath them. Some of the largest make an angle of less than 3° with the horizon, and move forward slowly without fracture or disturbance. A fall of 9° causes a rugged surface with numerous crevices, and one of 30° throws all into confusion and converts the stream of ice into a torrent of ice fragments. The termination of the glacier is ordinarily its steepest part; but the ice being then in a state of solution presents a different appearance. The advance of a glacier varies with the declivities of its course, with its magnitude and aspect, and with the season. It is slowest in summer and most rapid in spring. De Saussure in 1788 left his scale behind him near l'Aiguille noir (on Mont Blanc), and in 1832 it arrived at the Mer de Glace, a distance of 14,500 feet, in 44 years, thus descending at the rate of 330 feet in a year. M. Hugi, the most persevering of Alpine explorers, built in 1827 a hut on the glacier of the Aar. In three years it had descended 100, in nine years 714, and in fourteen years 1428 metres. Its rate was therefore 102 metres or 334 feet in a year. The ice has been in some cases found to advance at the rate of 52 inches in the 24 hours ; but this is about five times the general speed of the glaciers. For the descent, therefore, along the whole length of a primary glacier many years, in some cases above two centuries, are required. The secondary glaciers, though much steeper, are yet collectively slower than the primary, the resistance arising from friction increasing as the size of the glacier is diminished; many break off regularly.

The radiation of heat by a body is in general proportional to its surface. If two bodies of the same kind and equal volume, but differing in shape, be heated to the same temperature, and then left to cool, that which has the greater surface will be the first to part with its heat. The sphere is the figure in which the proportion of mass to surface is greatest; and therefore a hemispherical mountain would be that best adapted by figure for the conservation of its heat; and the larger its scale the greater would be its advantage. Reduction of size and irregularity of figure with angles and unequal dimensions all increase the proportion of surface to mass. Consequently small ramified mountains and narrow ridges part quickly with their terrestrial heat, while the lines of temperature rise on the flanks of great mountains and tablelands. This is well exemplified in the Œtzthal group of mountains in the eastern or Tyrolese Alps. This, the most considerable mountain group in Europe, occupies about 1000 square miles, and may be represented as a plateau or tableland 6000 feet high, with numerous crests and peaks ranging from 9000 to 12,000 feet in height. Its chief summits are the Wildspitz, Similaun, Weisskügel, and two of the Prochkügel; those of inferior height are 151 in number. It reckons 14 primary and 215 secondary glaciers. On these mountains (the furthest removed from the genial influence of the south-west wind) all the hypsometric lines marking temperature are raised 1000 feet higher than on the mountains in the same parallel further west. The snow-line ascends to 9600 feet, and several villages are to be found at the height of 6000 feet. It is obvious that the lines which mark the altitude of temperatures will run higher on that side of a mountain which faces the sun, and lower on the shaded side. Where the mountain has considerable breadth, so that its faces turned respectively towards and from the sun feel the combined effects of latitude and exposure, the changed altitude of those lines will be still more evident. Consequently the isothermal lines from north to south through Monte Rosa are found to rise on its southern face above 1000 feet higher than on the northern.

The humidity diffused in the atmosphere depends so much on temperature as to follow in general all its variations. Consequently it ordinarily decreases upwards, but not invariably; for on the sides of great mountains, in summer especially and in the middle of the day, humidity in its quantitative relation to temperature increases upwards, this increase being obviously the effect of an ascending current and of the evaporation of ice and snow lower down. The increase of humidity is most evident immediately over the snow and not far from its surface; and its excess is most observable in the morning and evening. At midday, when evaporation is most active and moisture is carried off the instant it appears, the air on the mountain is comparatively dry. Even bright sunshine seems to have no effect whatever on the snow; but the greatest dryness is at night, when all moisture has fallen from the air. In the free air, at a distance from snow or ice and on bare ground, the movements of the hygrometer are regular; and sometimes humid currents are dried by passing over glaciers which condense their moisture. On the Faulhorn (9280 feet) saturation is highest at noon when lowest in Zurich. On Monte Rosa (15,151 feet) the saturation at noon exceeds that in Milan in the proportion of 90 to 61. On the highest summits in general there is very little humidity, and therefore no precipitation. At 12,000 feet rain falls very rarely, and only in minute drops. Snow appears only as delicate stars and spicules or needles. The humidity met with on high mountains can be ascribed only to the occasional rising of the clouds. Cumuli are often seen above the highest of the Alps, and cirri at a much greater height. Transparent ice may at times be found at great elevations; but the water thus frozen does not originate in rain, but in the melting of snow by the radiated heat of bare rocks. The streamlets thus formed run down some 30 or 40 yards, and are often discovered from a distance by the visible vapour that overhangs them and marks their course. In general they are exhausted by evaporation before they have gone far; but if copious enough to form a pool this is quickly frozen. Though ice-water, being deprived of air, is unpalatable and indigestible, yet in flowing for a short distance over rocks it imbibes air and carbonic acid enough to make it drinkable.

Dew is more frequent though less copious on mountains than on low ground, especially in summer. Atmospheric humidity being of course first deposited where it first arrives at saturation the glacier is covered with hoar-frost on every clear night. Mists and clouds are never long absent from the High Alps. The latter rest during the morning at the height of 5000–6000 feet, and rise at noon to 7000–9000 feet. Clouds often gather suddenly on a mountain and as quickly disappear. The cirrostratus so frequent in the Alps has a thickness of 600–800 feet, and is said to exhibit agitation at its upper surface. The semicircular cumulus remains constant over great heights, even in spite of strong winds, being nothing more than the vapour of the ascending current gathering as fast as it is dispersed till it sinks at night. The cirri, the height of which has been variously and on insecure grounds estimated at from four to eight miles, do not sink. On Monte Rosa the ordinary cloud-region lies at the height of 5000–8000 feet, but with a south-east wind it rises to 8000–12,000 feet. In winter the humidity of the air decreases from the sea to the interior of continents; and in the latter it is most constant near the surface of glaciers, but with little elasticity.

Springs grow rare in the Alps at about 7400 feet, and in general disappear a little above the snow-limits or between 8500 and 9300 feet. They require not merely the presence of water, but also a mineral foundation capable of retaining it. Yet in Carinthia there is a spring at the height of 9450 feet; and in the side of the Gross Glockner (Tyrol), just above the snow-line, a spring darts forth at 9330 feet, where the mean temperature of the year is 37° Fahr. In the shafts of mines a little higher up there is no sign of water; the mean temperature of the highest is 31°·6. The fall of temperature in springs is found, as we ascend, to be slower than that of the air, and slower in valleys than on heights or slopes. At the limit of trees on the northern side of the Alps (6190 feet), the temperature of springs is 38°·3, or 3°·4 above that of the air. Thermal springs, however, are exempt from limitation as to height and temperature. A spring at Lenker, 4840 feet high, has a temperature of 170°. In general the temperature of springs in the Alps decreases 1° Fahr. for 426 feet. They are warmer than the air, the difference increasing with the height.

The temperature of the ground varies more slowly than that of the air, its local range being from 182 to 413 feet, or on an average 282 feet, for 1° Fahr. The decrease of temperature attending increase of altitude in air, ground, and springs may be represented by the figures 244, 282, and 400 for 1° F. Naked ground at great heights is often heated to 90° or 100° while the air is at 50°.

In the latitude of the Alps the sun's rays in summer might penetrate the ground at the level of the sea to the depth of 80 feet. But this heat, slowly communicated from particle to particle, takes six months to reach its limit ; and therefore at the depth just mentioned the summer heat is felt in winter, and that of winter in summer. As snow gets rid of heat by melting and evaporation, it is assuredly never penetrated by insolation to so great a depth ; but neither does it communicate heat so quickly as the ground. It is therefore extremely probable that often in winter, while the surface is frozen hard, there may be melting snow beneath, and that again in summer, when the surface softens, there is hard ice at the base.

CHAPTER XXIII.

Mountains—their Physical Influence—Steepness—interfere with the lower Atmosphere.—Temperature on Mountains.—Limits of Vegetation on the Alps.—Temperature of the Ice—Winds—Rains.—Decreased Amplitude of Variation.—Union of Heat and Cold.—The Andes—their Rains.—Himâlaya, its Rains.—Passes of the Alps, Andes, and Himâlaya.—Springs.—Lakes.—Mountain-dwellings.—Villages in Tibet.—Gold-Mines of Thok Jalung.—Table of highest Mountains.

THE physical influence of mountains necessarily depends in some degree on their magnitude, and is exhibited in various ways. 1st. Winds striking obliquely on a lofty range of mountains are liable to be reflected from them in an altered course. Thus the west winds from the Pacific Ocean, falling at an acute angle on the coast-mountains of California, are turned southward and become north winds. The height also and direction of the elevated land encountered determines the distribution of heat and humidity. 2ndly. The wind falling on a range of mountains is forced to ascend, and its moisture being thus condensed, precipitation ensues, and rain is poured prematurely and in excess on a narrow tract of country. The Ghats of Malabar and the Khasia hills in India, Sitka in North-western America, the coast south of Chiloe in South America, Bergen in Norway, Coimbra in Portugal, the hills of Cumberland, and the south-western Alps all furnish examples of unusual rainfall consequent on the interception of humid winds by hills or mountains. This excess shed on the hills entails deficiency on the plains beyond them. 3rdly. Since mountains offer different climates at different altitudes, they greatly increase the variety of productions within a limited area. 4thly. They rear and nourish rivers. For though some great rivers, as the Volga and the White Nile, flow from moderately elevated plains, yet most rivers, including the greatest on the earth (as those of South America, India, and China), owe their magnitude to the numerous streams poured into them from snow-clad mountains. 5thly. Mountains may be suspected of altering the thermal relations everywhere observable between the air and the ground; and on mountains of considerable mass the temperatures will probably be always found to differ from those deduced from latitude and altitude by defect, or still more by excess, according to exposure.

Of the magnitude of a mountain we derive our impression chiefly from its height; its other dimensions cannot be so readily measured by the eye. The ascent to a summit which stands before us, being foreshortened, is abridged to the view; and consequently the steepness of mountains from foot to summit is ordinarily much exaggerated by the imagination. Steep ridges and precipices may occur in the ascent; but then they alternate with glens and valleys, and the general result of these inequalities is a moderate increase of altitude in one direction. Thus the Alps and Pyrenees rise from the plain at an angle varying from 3 to 4 degrees. A carriage-road becomes difficult with an ascent of 5°, and impracticable with one of 7°. A man may be said to climb rather than to walk up an ascent of 30°. Etna, being a volcanic cone, standing on a base of 30 miles, with a height of 10,000 feet, is a steep mountain with a slope of 10 degrees; though only 2 miles high, it cannot be ascended in one day. The sides of volcanic cones often make with the horizon an angle of 30 degrees or more; but these form exceptions to the general character of mountains as exhibited in great ranges, and indeed the cone is generally but a small part of the mountain. Limestone-mountains often spring abruptly from low ground, and with precipitous sides spread out above into elevated plains, so that their altitude, compared with the area covered by them, is not unusually great. The more ancient rocks generally exhibit narrow ridges, much ramified, embracing deep spacious valleys, and occasionally shooting up into peaks. Level terraces occurring between these ridges or adjacent mountain-chains are often developed into wide tablelands. Thus the elevated plains between the Cordilleras of the Andes in Peru spread out to a breadth of 230 miles round the lake of Titicaca. Tibet is but an elevated valley between the ranges of the Himâlaya and Kuenluen; and, again, the high plain of Utah may be regarded as a raised valley between the Rocky Mountains on the east, and the Cascade range on the west. So gradual is the general ascent of mountains, that the altitude of a mile (5280 feet) can rarely be reached on them with a march of 10 miles. When we read therefore of travellers running up and down mountains 6000 feet high in two or three hours, we must regard their feats as something extraordinary; and when told that Kilima Njaro, in Eastern Africa, rising very gradually from a base apparently not exceeding that of Etna, yet attains double the height of the latter mountain, our astonishment gives way to incredulity.

It is the relative altitude of mountains or their height above the spectator that excites admiration. Their absolute height or elevation above the level of the sea is rarely cognizable by the eye, the mountain and sea or sea-level not being at once in the field of view; and consequently the impression made by the view of elevated summits is seldom in proportion to their absolute height. The highest points in the Himâlaya are never visible to the traveller till he has ascended several thousand feet; and often they are not fully revealed to view till their relative altitude has been reduced to a small fraction of their absolute height. Himâlayan peaks are at times visible from very distant points in the plains of India; and the volcanic cones of the Andes may in like manner be occasionally descried from a distance of 200 miles in the Pacific Ocean; but in these cases the distant snowy crests seem suspended in the air just above the horizon, and are curious but not stupendous objects. The mountain view which embraces the greatest altitude is that of Gaurisankar or Mount Everest, in the Himâlaya, 29,000 feet high. From Darjeeling, at an elevation of 8000 feet, it is seen towering to a height of four miles above the spectator; but even in this remarkable instance the magnitude of the object is diminished to the eye by 45 miles of distance. As an impressive spectacle, uniting beauty and grandeur in great variety of combination, and not too distant, the Swiss Alps probably do not yield to the loftiest mountains of the Old World or the New.

The traveller who ascends a mountain passes through successive strata of air, the temperature of which diminishes, because, first, being derived almost wholly from the radiated heat of the earth's surface, it must decrease as the distance from that surface increases; and, secondly, as the air becomes rarefied in consequence of diminished pressure, the heat inherent in its particles must be more diffused in space, and therefore decrease in proportion to its volume. The general rate of the decrease of temperature in ascending the Alps, supposing it to be uniform at all heights, varies with the seasons, being in January 417 feet, in July 260—the mean of the year, therefore, for all heights and seasons being about 318 feet for 1° Fahr. But the decrease upwards of atmospheric temperature as far as 16,000 feet, according to the accurate observations of Mr. Glaisher in a balloon, is only 254 feet for 1°; it would appear, therefore, either that mountains, by conducting the heat of the ground, raise the isothermic lines in the contiguous atmosphere, and have a higher temperature than would be found in the atmosphere on the same level at a distance from them, or else (which is more probable) that the presence of so much ice and snow forbids the gradual change that would take place in their absence, so that at 5000 feet (the general limit of glaciers) or at 8000 (where the névé begins) a low temperature and corresponding slowness of change is experienced, which in the absence of congelation would be first met with at a much greater elevation. According to Mr. Glaisher's Table, the decrease of atmospheric temperature at the general rate of 1° Fahr. for 318 feet occurs at the elevation of from 8000 to 20,000 feet inclusive.

The actual change of temperature attending ascent of the Alps varies so much with aspect, declivity, and other local circumstances, that no satisfactory account of it could be offered without running into details; but some estimate may be made of it from a glance at the vegetation. It hardly needs to be stated that the cultivation of the vine and cereal crops in Switzerland are to be found chiefly in the lower valleys, though not strictly confined to them. The extreme upper limits of each kind of growth will be seen in the following Table, respecting which it may be remarked that the highest figures refer especially to the western and southern faces of the Alps, to the Vaudois, and the slopes of Mont Blanc and Monte Rosa:—

		feet.		feet.
The vine and chestnut..............	from	1500	to	2750
Walnut..............................	„	2500	„	3700
Oak	„	3000	„	3500
Ash	„	3700	„	4100
Beech	„	4150	„	4800
Maple	„	4300	„	4500
Mean height of tillage	„	1800	„	5000
Extreme limit of tillage...........	„	3200	„	6000
Highest hamlets and homesteads	„	3000	„	6300
Alpine cabins	„	5500	„	7500
Pines and larch	„	5500	„	6500
Snow-limits.........................	„	8000	„	9500
Highest Phanerogams	„	10000	„	11000

This Table will be rendered more significant by comparison with the following one, due to the brothers H. and A. Schlagintweit, which shows the temperature absolutely necessary for the growth or successful cultivation of different productions :—

	Northern Alps.		Central Alps.		Southern Alps, Mont Blanc & Monte Rosa.	
	Height. feet.	Temp.	Height. feet.	Temp.	Height. feet.	Temp.
Turnips	1500	48°·2 F.	1800	47°·48 F.	2750	46°·7 F.
Walnut .... (mean)	2500	45·14	2700	45·14	3600	44
„ .. (extreme)	2900	43·8	3600	42·26		
Beech ...... (mean)	4200	39·38	3900	41·38	4800	39·5
Corn ....(mean)	2700	44·6	4000	41	4700	40·3
„ ......(highest)	3700	41·18	5100	36·9	6000	35·9
Conifers ....(mean)	5500	34·3	6000	33·6	6500	34·3
„ .. (highest)	6000	32·36	6500	31·21	7000	32·7
Snow-limits........	8200	28·3	8400	23·9	9300	23·9
Highest Phanerogams	..	..	10000	18·7	11000	18·7

Thus it appears that the zone, which has a mean temperature of 32° Fahr. (the freezing-point), lies between 6000 and 7000 feet and below the snow-line, which in summer may be found at an elevation of 7600 or 8200 feet, according to the circumstances of the ground, and in winter descends to the foot of the mountains. Of the winter temperature in the High Alps little is known, except that on the Finsteraarhorn (14,026 feet) has been observed a temperature of − 22° Fahr., or 54° below the freezing-point, and on the Jardin du Mer de Glace (Mont Blanc), at an elevation of 10,540 feet, − 6°·25 Fahr. It has been concluded that the mean temperature for the highest summits is from 5° to 8°·6 Fahr. The summer temperature observed on the summit of the Finsteraarhorn by Hugi was 26°·6, or 5°·4 below the freezing-point; but the heat in such cases may be greatly increased by the vicinity of naked rocks. Thus on the Grossglockner (12,431 feet) the thermometer has been known to rise to 95° Fahr.; but the solar heat, thus accumulated and radiated by the rock, has little effect on the air, and none apparently on the dry snow; it extends to a short distance, and is generally of short duration. A cloud or mist gathers over the heated spot, and all soon sinks to its original icy temperature. The temperature of the air in sunny weather on the mountain-sides may be assumed to be a little above the mean temperature assignable to the latitude of the place; that of the snow or ice increases towards the interior. Hugi sounded crevices to depths of 128 and 180 feet, and found that the temperature of the air above being from 1°·75 to 5°, that at the bottom had 20°·75 or 23°. Above the firn-line the temperature below the surface everywhere tends to rise to 32°, or the freezing-point; below that line, where melting may be said to begin, that temperature is probably maintained steadily in the interior by the water which, constantly dripping from melting ice or snow, permeates the entire mass.

Among mountains, where there is great variety of exposure, and where warm currents continually rise from below, while cold currents descend from the snowy heights, there often occur great differences of temperature, which give rise to atmospheric commotion. Wind is much more violent (*i. e.* rapid) at a great height than below; but, on the other hand, calms are more frequent above. Within the mountains the prevalent wind generally takes the direction of the chief valleys. These give it different directions, and consequently conflicting winds eventually arise from the continuance of a single strong wind. Snow-dust, raised in whirling clouds over the snowy peaks, then darkens the sky. The ascending currents attain their greatest importance in summer; and besides them many local currents play conspicuous parts, particularly when their violence is increased by a confined passage through narrow valleys. The prevalent wind in the Alps is the south-west, or what may be called the upper trade-wind of the northern hemisphere; this wind, called in Switzerland the Föhn (Favonius), begins very early in spring, or even in January, to blow on the Alps and to melt the snows. It is generally welcome, since it opens the pastures, though its first appearance is often attended with devastating floods and avalanches. As the Föhn often prevails above, while a cold north-east wind reigns below, many anomalies of temperature are thus explained, the High Alps being warmer and the valleys colder than might be inferred from general laws. There is most wind in March and November, the daily maximum occurring at noon; while the daily warm current ascends the hill-sides, a cold current descends the glacier close to its surface.

The Alps form the most rainy country in Europe, their south-eastern side excepted, where the rain-bearing south-western winds arrive exhausted. In the southern and western portions, autumn—in the northern, summer is the most rainy season. Hence there is often a marked difference in the productiveness of these two regions. Wet years give a good harvest in the south, dry years in the north. Again, on the south side of the Central Alps, bloom and harvest are later than in the north, because the Föhn or south-west wind in early spring is on that side accompanied by a very heavy fall of snow. No decrease of rain is perceptible in the Alps up to 5300 feet, though the limit above which snow may fall at all seasons is 5000. But above 5300 feet the decrease is evident; yet there are exceptions to this rule. St. Bernard (at 8160 feet) and St. Maria Helfseryoch (at 8070) have respectively no less than 59 and 79 inches annual fall of rain. In these instances the quantity of rain is increased, while the number of rainy days is diminished. The ordinary limit of pasturage on the Alps is 7800 feet. Rain is not totally excluded from the snow-region, where, however, it rarely falls, and above 12,400 feet only in minute drops. In winter there are many bright and calm days on the summits of the High Alps.

The amplitude or amount of the daily variation of temperature decreases upwards, as appears from comparing the range of the thermometers in Geneva and on Mount St. Bernard. The extremes of temperature are less above than below, and depressions congealing mercury, such as are experienced within the polar circle, are probably never felt on the summit of Mont Blanc ; but, on the other hand, sudden and irregular changes increase in frequency upwards. The atmosphere immediately over mountains, where the solar heat is very unequally distributed among the valleys, must be kept in continual agitation by frequent and violent efforts to restore equilibrium. The climate of the High Alps seems, in respect of temperature, closely to resemble that of lat. 70° N. as it is probably felt in Greenland; and in that parallel the temperature varies much on different meridians. It is mild south of Spitzbergen, rigorous over Asia and the American continent ; but these differ, inasmuch as the climate of Northern Asia runs more into extremes, while that of America is comparatively equable. The climate of the High Alps differs from both chiefly by fluctuating more within narrow limits. It is also worthy of remark that the extreme cold of the High Alps is often felt in the low valleys. The cold air descending by night fills the hollows, and in the morning the valley lies congealed, while the sun lights up the mountain-summits. The wintry north-east wind reigns below, where in the early spring the Föhn or warm south-west wind prevails above ; and in this case the summit of the Rigi has a much higher temperature than the town of Zurich at its feet.

At great altitudes the sun's rays coming unabated through a rarefied atmosphere have intense force, yet they do not warm the perfectly transparent air. The traveller scorched in the sun is frozen in the shade. He feels one side too hot, the other too cold. His face is burnt and blistered by the solar rays unless he wears a veil. In the Alps the guides and hunters prepare for excursions to great heights by rubbing their faces with flour ; in the Andes the usual practice is to blacken the face. The traveller breathing highly rarefied air, and thus losing much of the benefit of respiration, becomes incapable of continued exertion and suffers from distressing sickness. This malady (called in the Andes "Puno") affects different constitutions unequally. It sometimes proves fatal ; but in general it abates with time and patience, and men can not only live but even labour at great altitudes.

The Andes along the western side of South America have an extent of 55 degrees, or about 3790 miles. Towards the equator in Bolivia and Peru they divide into two, and for a short distance into three chains or Cordilleras, embracing between them plains of great elevation. Of these, the most important lies round lake Titicaca in Bolivia, sloping gently towards the south, with an elevation varying from 14,000 to 12,000 feet, and a breadth never exceeding 230 miles. This is the portion of the Andes which may be most advantageously compared with the Swiss Alps. The great mass of land enclosed by these branching Cordilleras conduces to a general rise of temperature ; and consequently we here find a town (Cerro de Pasco) in which the labour of mining is carried on at the absolute height of 14,280 feet. The miners here have to climb ladders from deep shafts, while they carry up basket-loads of ore—a surprising exertion in the Puno or rarefied atmosphere, in which the stranger feels himself quickly sickened or exhausted by the least effort.

The rain-bearing winds in the Andes come from the east, and have already parted with much or most of their humidity before they reach the mountains, where the most eastern Cordillera, being the first met with, wrests from them nearly all that they still retain. The most western chain receives but little snow or rain ; and the western slope of Peru, from the Andes to the sea-shore, is a dry country, rescued from total barrenness only by the humid mist that hangs over it for some months in the year. Again, the highest summits in the Andes are all volcanic, and therefore have the steepness and uniform slope peculiar to mountains of that class. Notwithstanding their elevation, therefore, into the regions of perpetual snow, they have no glaciers, because the form and steepness of the snowy heights allow the rapid descent of the snow to the line where it melts, and there is no reservoir of snow at greater heights to supply the waste ; but at the extremity of the continent, from Chiloe southwards, where with low temperature there is a superabundance of precipitation in the form of snow, the mountains, though comparatively low, are covered with perpetual snow, and numerous glaciers descend to the level of the sea; but with these we have as yet no intimate acquaintance.

The Himâlaya Mountains enclose the peninsula of India on the north as the Alps do that of Italy. They have a length of nearly 2000 miles from N.N.W. to E. S.E., and do not terminate abruptly, but may rather be said to continue with change of name and of direction also on the east. They form the southern border of a very elevated region, bordered on the northern side by the Kuen Luen mountains, the Karakorum range also extending in a parallel direction, on the west, between the other two. Some give the name Karakorum only to a single mountain-pass; but it seems more convenient to extend it to the line of lofty crests which mark the watershed between Turkestan and Western Tibet, separating the basin of the Indus from that of the river of Yarkand. Further east the Brahmapootra at a great height divides the valley between the Kuen Luen and Himâlaya. This valley being very elevated ground, the two mountain-chains just named, though geographically separable, are in fact intimately associated, being the outer edges of a vast extent of elevated land having an average breadth of perhaps 200 miles. The highest points of the Himâlaya do not lie on the main axis of the chain or at the division of the waters, but further south, being for the most part the terminations of spurs which jut southwards from the axis. They surpass in height the summits of the Kuen Luen, which chain, however, probably exceeds them in mean elevation.

Rain is carried to the Himâlaya by the S.E. monsoon, and falls heaviest on the Khasia hills, which first rise to intercept it at the head of the Bay of Bengal. The further it advances to the north and west, the more scanty it becomes. Thus the Alps differ from the great Asiatic chain, inasmuch as they have most moisture at their western end, and their northern face touches on a climate which has rain at all times of the year. The western end of the Himâlaya overhangs parched plains very scantily watered, and extreme dryness is the characteristic of Western Tibet. On these mountains glaciers are numerous and of enormous extent; but they rarely descend to the closely inhabited country. Very few are to be seen below the elevation of 10,500 feet. Most of the rivers in the Tibetan plains have their sources in glaciers.

In the Alps the mean height of the passes is 7550 feet; in the Andes very few passes exceed 14,500 feet, though the Alto de Toledo and the Lagunillas have an absolute height of 15,590 feet; but the passes of the Himâlaya have a mean height of 17,800 feet. The height of the Mustagh pass in Garwal is 19,019 feet, while that of the Ibi Gaman (in the Himâlaya), a pass deemed practicable half a century ago, is 20,459 feet. The brothers Schlagintweit, while exploring the glaciers of Ibi Gaman, spent ten days (August 1855) at very unusual heights about this pass, their lowest camp being at 16,642 feet, their highest at 19,094 feet. They spent two nights at a height of 18,300 feet, and ascended the flanks of the mountain to 22,259 feet, the greatest altitude yet attained on mountains.

The highest passes in general use are:—Porang (Spiti), 18,500 feet; Mana, 18,406; Karakorum, 18,345; and Kiobrang, 18,313. Over these passes there is no made road; the way is marked only by stones and the skeletons of those who have perished on them. Passes above 16,000 feet high on the Himâlaya are closed from November till May. On the Karakorum, where there is little snow, the passes are never wholly closed in winter; on the Kuen Luen all passes above 15,000 feet are then barred.

The highest cold spring in the Alps is found at 10,440 feet. In the Andes the spring known as the "Ladera de Cadlud" rises at the altitude of 15,525 feet; but on the slopes of Kyungor in the Himâlaya is a spring at the height of 15,920 feet, and on the northern side of Ibi Gaman, in Tibet, there is another at the height of 17,650. Springs at high temperature are frequent at the elevation of about 6000 feet; and some are found even on the elevated plains of Tibet. Lakes, too, are found in the Himâlaya, chiefly between 5000 and 6500 feet; but they are less frequent than the beds of former lakes, now dry and filled with salt. On the plains of High Asia, however, between the Himâlaya and Kuen Luen, lakes are numerous. It will be sufficient to name the following:—

	Altitude.
Aksai Chin	16,620 feet.
Tso Giagar	15,693 „
Tso Kar	15,684 „
Mure Tso	15,517 „
Kiük Kiöl	15,460 „
Rakus Tal	15,250 „
Mansarhur	15,250 „
Tsamoriri	15,130 „
Nima Kar	15,100 „
Tso Gam	14,580 „
Tso Rul	14,400 „
Tsomoguelari	14,600 „

Shepherds' huts for summer dwellings are rarely met with in the Alps at heights exceeding 8000 feet; in many favourable situations towards the south, about Monte Rosa, they may be occasionally found at 9000. In Tibet temporary habitations with stone walls are found at the height of 16,500 feet on the summer pastures; and men may remain some days at still greater heights without injury, though strangers are painfully affected by breathing the rarefied air. Gartok in Tibet, a summer village or town (in lat. 31° 40′ N., long. 80° 18′ E.) with an important annual fair in August, stands at the height of 15,090 feet; but near the lakes, where salt and borax are collected, are the villages of Puga and Norbu, at the heights respectively of 15,264 and 15,946 feet, the former exceeding Monte Rosa, the latter Mont Blanc, in height. It was long supposed that Hanle, a Buddhist monastery in Ladak (lat. 32° 48′ N.) at the absolute height of 15,117 feet, was the highest permanent habitation in Tibet; but recent exploration has found communities established at a much greater elevation. A well-instructed Pundit, sent from India in 1867 to endeavour to penetrate, if possible, the desolate plains and recesses of High Asia, going eastward from Gartok, crossed several high passes, among others the Gugti-la, 19,500 feet above the sea; and travelling about twenty days over rugged plains, never less than 15,000 feet in elevation, he descended from the Chomorang-la pass (18,760 feet) to the encampment in the gold-fields of Thok Jalung.

These are at the great elevation of 16,330 feet. The miners live in tents pitched in pits about 7 feet deep and covered with felt. The work of mining is carried on to a depth of 25 feet, chiefly in winter, because the ground is then firm, and pits do not fall in; perhaps also because the dry cold of winter, though intense, is less insupportable than the united cold and humidity of summer. Whatever be the reason, the encampment at Thok Jalung, at a height of more than 3 miles above the level of the sea, increases in winter to 6000 tents, or probably 20,000 souls. The gold-mines, in territory subject to the Chinese, are very productive.

The following Table exhibits side by side some of the loftiest mountains of Europe, Asia, and America:—

Alps.	feet.	Himâlaya and Karakorum.	feet.	Andes.	feet.
Mont Blanc..	15,784	Gaurisankar..	29,002	Aconcagua ..	23,004
Monte Rosa..	15,223	Dapsang	28,278	Sahama	22,350
Taschhorn ..	14,954	Kunchinjinga	28,156	Parincota	22,030
Weisshorn ..	14,813	Sihsur	27,779	Gualatieri ..	21,960
Mount Corvin	14,787	Dhavalagiri ..	26,826	Pomarape ...	21,700
Dent Blanche	14,305	Yassa	26,680	Chimboraço..	21,422
Gd. Combin..	14,134	Jibjibia	26,306	Sorata	21,286
Strahlhorn ..	14,100	Barathor	26,069	Illimani	21,145
Finsteraarhorn	14,039	Yangma	26,000		

Gaurisankar, 5½ miles high, the loftiest measured mountain on the earth (called by the Tibetans Chingopamari), is the Mount Everest of English maps; it stands in Nepaul, in lat. 27° 59′ N., long. 86° 54′ E. In the Hamâlaya alone there are now measured 216 peaks, of which 17 exceed 25,000 feet, 40 23,000, and 120 20,000 feet in height. The snow-limit on the southern face of these mountains is throughout at an elevation of about 16,000 feet, on the northern side it rises 4000 feet higher. Glaciers of great extent, 40 or 60 miles in length, fill the upper valleys, descending on the west to the height of 11,000 feet, on the east to 14,000 feet. Heaps of boulders, evidently ancient moraines, occur frequently at the height of 9000 feet. Snow falls down to 9000 feet, and even, though very rarely, to 5000. The great rivers that descend from the Himâlaya all have their origin in glaciers. The Kyang (or wild horse) and the Yak (or wild, long-haired cow) rove over the desolate frozen wilds, and are most numerous at the height of 19,000 feet.

CHAPTER XXIV.

Electricity—how developed—its Nature and Power.—The Electroscope.—Atmospheric Electricity—its Daily Variation—most abundant in Winter—identified with Lightning.—Dr. Wall, Franklin, Richman, &c.—Clouds as electrical Conductors.—Thunderstorms.—Fogs.—The Path of Lightning.—Fulgurites.—Height of Thunder-clouds.—Periodicity of Electricity—Illustrated.—Fireballs or Thunderbolts.—Singular Effects imputed to Lightning.—Lightning-rods.

The atmosphere is never wholly devoid of electricity, which, however, ordinarily remains latent. By the development of electricity is meant the separation of two principles, generally called positive and negative, by some vitreous and resinous electricity, which separately exhibit the phenomena of attraction and repulsion, constantly tend to unite, and by uniting are extinguished. If a vitreous body, as a tube of glass, be rubbed with silk, it becomes positively excited, the negative electricity remaining on the silk. If a piece of gum-lac be rubbed with the hand or with woollen cloth, it retains the negative or resinous electricity, leaving the positive on the hand or cloth. The electricity thus developed may be communicated to a receiver made of a conducting or non-electric substance, and insulated by means of a non-conducting or electric support. Metals and humid bodies are all conductors, glass and gum-lac are electric and non-ducting substances ; dry air, too, belongs to the latter class. Consequently a brass cylinder without sharp edges and supported by a pillar of glass or resin is in dry air an insulated receiver, and will retain for a considerable time the electricity imparted to it.

If this receiver or conductor be touched with the hand or any conducting body communicating with the ground, its electricity will be instantly discharged ; but if another similar insulated conductor be placed before it at a little distance, the electricity of the latter will be developed. In this case there is no communication ; the first conductor loses nothing of its charge. It operates by what is called influence or induction ; and the induced electricity in the second conductor has this peculiarity, that it is of both kinds, the negative fluid being collected on the end presented to the positive electricity of the first conductor, and the positive electricity of the second conductor flying to the other end. One of these induced electricities may be withdrawn and the other allowed to remain. By this power of induction, the phenomena of atmospheric electricity are rendered very complicated ; and negative electricity is often found where positive might be expected, and *vice versâ*.

The two kinds of electricity attract each other, and in the effort to recombine them it exhibits all its force and fire ; but confined to one kind it is violently repulsive. If a brass wire be passed through the cork of a phial and two slips of gold-leaf be fixed to its lower end, the instant the upper end is placed in contact with a charged electric conductor the slips of gold-leaf will diverge, repelling each other ; and by the degree of their divergence may be measured the strength of the repulsion. The strength of electricity shows itself in rending, splitting, scattering, chemically decomposing, and in the melting of metals, all various forms of repulsion.

By means of the instrument just described, which is the simplest form of the electroscope, atmospheric electricity may under favourable circumstances be easily detected ; not, however, among houses or trees, nor anywhere close to the ground, but in calm weather, with a clear sky, the electroscope will show at five feet from the ground the presence of positive electricity, and the higher it is raised the plainer will be its indications. It is, in fact, ascertained that the ground is always negative and the atmosphere positive, the positive electricity increasing higher up, so that on lofty mountains in clear weather it becomes luminous, and travellers may often see and feel it. But whence comes this electricity ? Some have suggested that it is an effect of evaporation. M. de la Rive held that it originates in the centre of the earth, from the action of the internal fires on the surrounding minerals ; that this gives birth to the negative electricity of the earth, which induces the positive condition of the atmosphere. But M. Pouillet found that while the evaporation of pure water gives no sign of electricity, water containing any acid, when evaporated, gives out positive or, with an alkali, negative electricity. He thence concluded that the atmosphere owes its electricity to the evaporation of the sea, that of the ground being thence induced. This explanation of the matter is doubtless the least objectionable of those offered, and is now generally received ; but it must be remembered that electricity is most abundantly developed by the friction of non-conducting or electric bodies, as glass, gum-lac, silk, hareskin, &c., and that dry air is one of this class. The agitation of the air with aqueous particles sufficiently accounts for atmospheric electricity. Trombes and waterspouts are highly electrical.

By careful observations with the electroscope it has been found that the electricity of the atmosphere has a daily and annual variation. Twice in the 24 hours (viz. at 10 o'clock in the morning and evening) it has a maximum, and twice (at 2 o'clock in the afternoon and at night) a minimum. The hours of change, however, are found to differ in different places. These changes are traceable, not to fluctuations in the quantity of electricity, but in the means of communicating it. Dry air does not conduct electricity, humidity does. The dew upraised in the morning and falling after sunset occasions the 10 o'clock maxima. Dissipated by day and laid at night it is followed by a period of dry air, which brings on the minimum at 2 o'clock. From these observations also has been drawn the unexpected conclusion, that the atmospheric electricity of winter far exceeds that of summer, as will be seen from the following results of observations made in Brussels in 1846 (the figures give the amount of the angular deviation caused by the electricity of a magnet suspended in the electroscope) :—

January	562°	July	33°
February	256	August	57
March	95	September	62
April	94	October	98
May	49	November	274
June	39	December	799

When Dr. Wall related in 1706 (in the 'Philosophical Trans-actions') his discovery of the electric spark, he could not help adding the remark, "It seems in some degree to resemble thunder and lightning." Yet the identical nature of the two phenomena remained unproved till Dr. Franklin in 1752, by flying a kite, drew a spark from the clouds. The results obtained by him were feeble, though sufficient to demonstrate the existence of atmospheric electricity; but in the following year the same experiment was repeated with care and success by M. de Romas, who drew from the atmosphere sparks nine feet in length. Soon after Professor Richman, of St. Petersburg, collected the electricity of the clouds, and incautiously approaching the conductor was killed by the discharge.

The attention of Franklin and of his immediate followers was directed wholly to thunder-clouds; but it is now perfectly understood that the atmosphere is at all times charged with electricity, which if not more developed is at least more easily and plainly observable in calm weather and under a clear sky. We have seen that vapour, taking the gaseous form, becomes much lighter than air, and favoured by the decrease of pressure ascends to a great height in the atmosphere. It thus enters the sphere of the strongest positive electricity; but the instant that it changes into fluid molecules it is invested with electricity, of which water is a conductor. Consequently the molecules, having all the same electricity, repel each other, and repelling the dry air also, they obtain buoyancy at a certain elevation. In this condition they form a cloud. Having descended from its birthplace the cloud may possibly feel the effects of induction and be negative above, while its positive electricity, still predominant, faces the earth. Its electric tension is thus increased; but in this state a cloud may be regarded as a charged conductor with its electricity on its surface. Now it has been already shown that clouds may, in consequence of induction or contact with land or through a fall of rain, change their electricity and be either positive or negative. The sun's heat causes ascending columns of air and vapour that carry with them the negative electricity of the ground. The clouds thus formed are attracted towards and clash with those from above of positive nature; a thunderstorm ensues and the two electricities combine. Clouds in thunderstorms are charged conductors of electricity, but they are flexible conductors ; the electricity is not equally spread over them, but has greater tension at every prominent point, or where there is a larger proportion of surface. These all hurry forward to meet the foremost points of the opposite array. Hence the commotion and rapid change of figure observable in clouds during a thunderstorm.

From what has been said it is easy to understand why thunderstorms are almost strictly confined to the hottest months of the year, and in the torrid zone, where they are constant, to certain hours of the day. The decline of daily heat on the ground begins between 2 and 3 o'clock, growing later as the heat is intense and the exposure perfect. Up to that hour, therefore, continues the ascent of heated air and vapour, the latter laden with the negative electricity of the ground ; but in the upper regions of the atmosphere the decrease of the sun's power commences much earlier and the vapour begins to sink. The opposite electricities thus destined to meet seize on all the vapour, and thus acquire compactness and solidity. The opposing masses of clouds then rush together, flashes of lightning discharge the electricity while thunder rolls, till all being expended, and the clouds having lost their support, rain falls in torrents. These thunderstorms with deluges of rain are in tropical countries witnessed daily, at precisely the same hour and in all circumstances alike. They seem to suggest that without clouds electricity would not be formidable, and that without electricity clouds could not exist.

Clouds and fogs never appear without disturbing the electricity of the atmosphere. If they do not change its character, they at least alter its distribution. The electricity of fogs is always positive, and generally has considerable tension ; hence luminous fogs are said to be not uncommon. Storm-clouds are easily distinguished by the rapid manner in which they come together. Their peculiar darkness is probably due to the circumstance that while there are two strata of clouds, one over the other, their vertical dimensions have been increased by their mutual attraction. The electricity of salt water being the same as that of the atmosphere, thunderstorms are much less frequent at sea than on land. Between the tropics thunder is heard almost as often as the clouds gather ; and at particular spots, where the configuration of the ground and the prevailing winds tend to congregate vapours, thunderstorms may be witnessed every day in the year. The extreme violence of thunderstorms seems to be exhibited in the densest, consequently the lowest regions of the atmosphere ; on elevated tableland they are comparatively feeble though frequent.

The thunder-cloud being assumed to be the electric conductor, the lightning will be its spark. The general belief seems to be that the lightning proceeds from the cloud to the earth ; but this may be contested. Electricity seems to have a binary nature with polarity. Neither positive nor negative electricity can start into existence alone, neither can precede the other ; the spark that unites both poles must leave them simultaneously. Were it possible to trace the progress of so rapid a phenomenon as lightning, doubtless simultaneous flashes from the cloud and the earth would be seen in the middle. The electric tension of the clouds is at once responded to by like tension in the electricity of the earth ; but on both sides the direction in which the electricity endeavours to escape depends in some degree on its distribution over the surface, and therefore on the form of that surface ; it is also probably influenced by the humidity of the air, not equally diffused but grouped in masses. The electricity on both sides, therefore, is swayed by two forces, an external attraction and an internal impulse. The attractions do not operate alone, but mix with disturbing impulses, and therefore they deviate from the direct and shortest line ; but when they approach each other, a flash across, often at a very acute angle, connects them. Such is the zigzag course of lightning in the simplest form. The spark that passes between the conductor of an electric machine and a well-turned brass ball is always straight ; but if a piece of zinc with jagged edges take the place of the ball, the spark will be much longer than before, and as angular as any flash of lightning. The irregular surface of the zinc has altered the character of the spark. If to the influence exerted on what may be called the presentment of the electricity at its starting-point and that of partial humidity be added the condition that the spark leaves the opposite electricities simultaneously, there will be no difficulty in accounting for its capricious course or that of lightning. If angular zigzag lightning be supposed to proceed from one pole to the other, then some portion of it must be retrograde ; if we suppose it to start at once from both poles, those portions, generally short, need not be retrograde, but will serve to connect direct lines from one or the other pole.

When lightning strikes the ground without dispersion, it sometimes fuses the sandy soil or rock, and leaves as a mark of its passage what is called a fulgurite ; that is, an imperfectly vitrified tube, from 10 to 30 inches long and 3 in diameter. Fulgurites have been often dug from the spots where lightning was seen to strike. They are said to be numerous in the plains near the mouth of the Rio de la Plata. Perhaps the abundant electricity developed over the Pampas is most attracted by that part of the plain where, while the air is still dry, the ground begins to acquire conducting-power by the infiltration of water from the river ; but the spot on the earth where fulgurites are most frequent is Little Ararat, a mountain about 13,007 feet high, with peaks of bare sandstone. A little to the west of it, the rounded summit of Great Ararat, 17,210 feet high, and covered with snow, serves to collect the electricity, which from time to time is discharged upon the naked rocks of the neighbouring mountain.

As the electric spark represents on a small scale a flash of lightning, so the cracking sound is a weak copy of a clap of thunder. But the spark issues from a firm brass conductor, the lightning from a loose electric cloud, which recoils from the shock of the discharge and vibrates from end to end. These vibrations, following the first acute-sounding clap and arriving in succession from increasing distances, constitute the peal of thunder, which varies with the distance, volume, and density of the vibrating section of the cloud. If the time that elapses between the flash of lightning and the thunder-clap that follows it be carefully noted, and the number of seconds be multiplied by 1123 (the distance in feet travelled by sound in a second), the product will give the distance of the cloud ; and if the altitude of the flash be at the same time observed, then its height above the earth will be known. And, again, the distance of the cloud whence the lightning proceeds being known, an observation of the angular space in the heavens or on the horizon embraced by the flash may furnish the means of calculating its absolute extent. Thus M. Ant. d'Abbadie estimated that lightning seen by him in Abessinia played at once over a region of 100 miles in breadth. But here it may be remarked that it is not easy to distinguish the flash of lightning itself in the horizon from the illumination caused by the flash on the edge of a bank of clouds.

The height at which thunderstorms take place varies from the surface of the ground to 16,000 feet, or above three miles, but ordinarily they rise no higher than 3000 feet. According to Humboldt and Boussingault thunder at night is almost unknown in equinoctial America. Storms there always take place in the afternoon, and are over by sunset. Thunder grows rare towards the poles, and is never heard at sea beyond lat. 75°.

The electricity of the atmosphere is attracted by points which offer to conduct it to the ground, and which are more attractive if metallic or humid. Hence it often strikes trees, tall chimneys, church towers and steeples. The force with which it splits and tears to pieces great trees or other non-conducting bodies is ascribed by some to the moisture in them converted into steam by the intense heat; but the violent repulsion of bodies or parts of bodies charged with the same electricity offers a sufficient and more natural explanation. We read of large masses of masonry carried some distance by lightning; but in truth they are flung, not carried, to a distance. Of the singular effects of lightning many instances are recorded. M. Ant. d'Abbadie relates that 2000 goats, driven for shelter into a cave in Abessinia, were all killed by a single stroke of lightning. Some years ago it was stated in the French papers that a regiment on the march near Lyons was completely prostrated by lightning, the men being all thrown down in succession, but none killed.

It has been suggested by M. de la Rive, a very great authority on these matters, that electricity has a tendency to flow in waves; that is to say that, alternately spending and accumulating, it is periodical in tension. In proof of this suggestion may be adduced some instances of a kind unknown to its author. At Graaff Reynett, in the eastern division of the Cape Colony, the court-house was some years ago struck by lightning, and the bell-wire running through the building, and altogether about 80 feet in length, fell to the ground, cut into small pieces of equal length (about three quarters of an inch). A precisely similar occurrence has been since witnessed in a workhouse in the north of England. Narratives of a seemingly marvellous kind deservedly meet with little attention; but the account of what took place in Graaff Reynett is here given on the authority of a witness of the highest character, who was in the court-house alone when the accident occurred, and saw the wire fall in pieces. Here is a plain instance of periodicity. What determined the periods or length of the waves? Might it not be that the interval between the first two supports of the wire where it entered the building was an aliquot part of the whole?

To the ordinary sources of atmospheric electricity must be added volcanic clouds or exhalations, if these be not rather the causes and conspicuous accompaniments of agitated dry air. Lightnings have been seen to play for several days together without intermission from the black clouds formed over Vesuvius after an eruption; and the fiery energy of these clouds has been felt at Tarento, 250 miles from the place of their origin.

There are no meteors more formidable and unaccountable than those popularly called fireballs. Their frequent occurrence and dangerous character are well attested; yet nothing is known with certainty of their nature. In some foreign languages they are confounded with strokes of lightning under one name; hence they are generally considered as or classed with electric phenomena; but compact electricity, hovering slowly in the air, apparently without either attraction or repulsion, rolling on the ground and then suddenly exploding like a bombshell, is a compound of contradictions hardly conceivable. It is for chemists to decide whether gaseous matters generating electricity may not by some means be concentrated in the atmosphere and explode by mixture with oxygen gas at a certain stage of their combustion.

Cases have been stated of lightning stamping on bodies struck by it the figures of objects at a little distance. Thus a man killed by lightning is said to have been marked with lines exactly representing a tree near the spot. This may be partially true; such a figure may have been drawn, but it was not a copy.

It is ascertained that persons struck by lightning are often marked with ramified figures, determined perhaps by the vascular structure of the body. It is also stated that the figure of a horseshoe was imprinted on the body of a man killed by lightning opposite to a door on which was nailed a horseshoe. Though such statements cannot be positively denied, it is not easy to believe them, and science ought to distinguish the certain from the doubtful. M. Arago, whose authority may be cited for the use of the name lightning-balls, showed his caution when writing it by adding, "or, if the reader pleases, certain luminous masses."

Lightning is intense electricity, flying to be discharged or extinguished by union with electricity of the other denomination. This it seeks in some cloud or on the earth. It prefers surface, and accordingly points having the greatest proportion of surface to solid specially attract it. When directed to the earth it is most disposed to strike prominent and pointed objects. High towers and church-steeples (the latter especially when surmounted by a vane and windrose of iron) are liable to be struck by it. The iron, or in its absence humidity, conducts the electricity to the non-conducting materials, which, rendered mutually repulsive, break asunder. Trees also often serve to connect the lightning with the moist ground; but the dry, non-conducting, internal wood is split and torn to shreds. Animals are killed by the severity of the shock, and, if the lightning enters the body, by its heat; for when electricity encounters resistance it burns its way through. Men and animals often perish in thunderstorms in consequence of their taking shelter under trees.

But the danger to be apprehended from lightning may in general be easily averted by means of lightning-rods or *paratonnerres*; that is to say, by iron rods affixed to the most prominent part of the building to be protected, and connected with the ground by metallic chains or bars. This simple precaution, however, often proves ineffectual, owing to the defect of the conductor; for if the metal rod or chain be too small, it is liable to be melted by the lightning; and if it be not sunk deep enough in the ground to reach moisture, it fails to carry off the electricity.

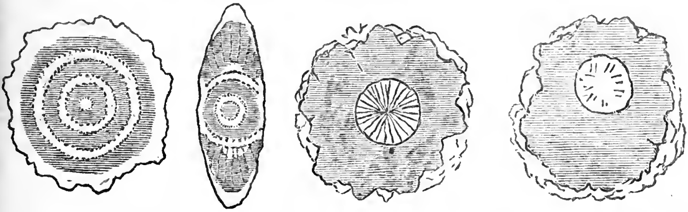
CHAPTER XXV.

Hail, unlike Snow.—Hailstones, Peculiarities of—unequally Distributed —Destructive—singular remark of Von Buch.—Great Damage done to the Vineyards of France.—Influence ascribed to Forests.—Attempts to explain the Origin of Hail—Volta—M. de la Rive—M. Dufour.—Intense Cold the first Condition—this produced by the rapid Expansion produced by an Electric Discharge.

HAIL, though it resembles snow in being merely water congealed, differs from it essentially and in many respects. Snow exhibits in its delicate, symmetrical forms the effects of the undisturbed crystallization of vapours suspended in the atmosphere. Hailstones, on the other hand, resemble fragments of rough ice, or perhaps flakes of snow collapsed by partial melting and then frozen in one mass. Snow is the usual consequence of a certain degree of reduced temperature attending change of season; it falls gently, and covering the ground, protects it from intense cold, being at once a progeny and a moderator of low temperature: but hail occurs more frequently in spring and summer than in winter, and often falls with destructive violence, doing irreparable injury to fruit-trees and vineyards; being usually the accompaniment of thunderstorms, it is assumed to be an electrical phenomenon. In Iceland it is particularly frequent during volcanic eruptions.

The origin of hail is extremely obscure; nor is it easy to account for the complex formation of hailstones. They are

Fig. 100.



sometimes nothing more than small masses of ice or collapsed snow; but they more frequently have a nucleus of this kind surrounded by a coat of ice radiating from the centre (fig. 100), or they exhibit concentric coats of ice wrapped round the nucleus, the regular structure being occasionally covered with angular masses of ice. It is said, too, that hailstones have ordinarily a protuberance on one side, so as to resemble in some degree a pear or a mushroom. Their usual size is less than that of the hazelnut: but they are often much larger; and, indeed, there are many authentic accounts of hailstones of formidable magnitude, as large as eggs, or even as oranges. Large masses of ice often fall with the hail. It has been stated that after a heavy fall of hail in Hungary, it was found that the hailstones all contained a small concretion of meteoric iron. In this case it can hardly be doubted that the consolidation of the iron and congelation of its watery covering took place together.

Hail is more partial as well as much less frequent than rain. It seems to be comparatively rare in the plains of the equinoctial regions at elevations less than 2000 feet above the sea—a fact not to be accounted for merely by the heat of the lower regions of the air, since it falls frequently in Southern Europe in summer, when the temperature equals or exceeds the mean temperature at the equator. The cold of the polar regions does not render it frequent; and, in short, its ordinary occurrence is in the temperate zones. Hailstorms appear, in Europe at least, to run in narrow lines, not averaging above half a mile in width, and chiefly from S.W. to N.E. Sometimes their course is at right angles to the preceding, or from N.W. to S.E. The great hailstorm which devastated France in 1788 travelled from the western Pyrenees to the Baltic Sea, a distance of 600 miles, in two lines, about 8 miles asunder, and respectively about 8 and 4 miles wide. Some of the hailstones that fell on that occasion had a diameter of not less than 3 inches; a few had a bulk of 70 cubic inches. The storm passed on at the rate of 40 miles an hour, the fall of hail at each point lasting 7 or 8 minutes. In May 1834 Russia was visited by a very extraordinary storm of hail, which in less than six hours extended over a region embracing 15 degrees of longitude and 10 of latitude, from the

Dniester to the Volga, and from the Baltic to the Black Sea; but in the middle of this region the government of Orel escaped almost untouched. At St. Petersburg the hail was very small, and attracted attention for its novelty, being there almost unknown; but it increased in size towards the S.E., and at Kherson the hailstones weighed from three ounces to three quarters of a pound.

Some places seem particularly liable to the ravages of hail, from which others at no great distance are exempt. Clermont in Auvergne suffers annually from this scourge, while the parish of Vernet, at a distance of only two miles and about 1200 feet higher, hardly feels it once in twenty years. It is most to be dreaded in the close vicinity of mountains and at the foot of narrow ridges. Leopold von Buch ventured to make the startling announcement that hail avoids valleys in which goitre is prevalent; and his statement, though made in terms that misrepresent the natural principle of the phenomenon, appears to have some foundation. It is said that in Switzerland hail falls rarely in valleys that run east and west, but frequently in those stretching north and south. Neither does it fall in deeply enclosed valleys, so far justifying Von Buch's views; but it is often felt severely just where the valley opens to the plain. Thus, for instance, at Borgo, at the lower entrance of the Val d'Aosta, the havoc annually made by it in pastures and plantations is regarded as a matter of course.

France (in whose productive economy vineyards hold so high a place) is the country that suffers most from hailstorms, which take place generally at the very season when the vines are most likely to be irreparably injured. Attention has consequently been there directed to the course of hailstorms, and the means of averting them. Much reliance was placed some years ago on *paragrêles*, or lightning-rods erected about vineyards, to disarm the clouds by carrying off the electricity; but this expedient failed, for obvious reasons. A paragrêle in a vineyard could avail only to bring down the storm on the spot which it was meant to protect. The proprietor of the vineyard could not place it a mile or two to windward, where it might possibly have proved efficacious. At present the belief seems to prevail that hail while desolating the open country avoids the forests ; but it must be observed that the hailstorm which can batter and destroy a vineyard, may be unable to leave any permanent marks of its attack on a forest. An eminent writer, M. Becquerel, who believes in the immunity from hail enjoyed by forests, endeavours to account for it in the following words :—" Their influence may be ascribed to two causes : they impede the lower currents of air which carry the clouds, and thence follow eddies in the moving masses, and a rush of air with a portion of the clouds, either along the margin of the wood or to a height above it. The speed of the wind and of the cloud being thus checked, a fall of hail may take place before the clouds reach the forest." Again, he says, " In the hot season the exudation of the foliage supplies an ascending current of vapour, and this reaching the clouds, places them in communication with the trees, and thus the electricity reaches the ground."

M. Becquerel's first argument is that the electric clouds cannot reach the forest ; his second is that they do reach it, and that it serves as a paragrêle ; but why it is more successful than the ordinary paragrêle is not explained. The maps constructed to show the distribution and ravages of hailstorms exhibit no symptoms of natural law. The hail does not seem to spare small woods, but only the great forests ; and it has no mercy on the villages lying within or on the borders of the latter. It seems likely, therefore, that the ravages of hail are most noted and calculated where they are most important, which certainly is not in the forests.

The attention of those who sought to account for the phenomena of hail was soon directed to its apparent connexion with electricity ; and Volta explained the formation of hailstones by supposing globules congealed by the cold of evaporation to be repeatedly thrown up and down between two strata of clouds at different altitudes and with opposite electricities and by this shuttlecock play to attract moisture and increase in size till they can be no longer supported by electric attraction. This theory, though long in vogue, rests on assumptions so arbitrary and unnatural, that now it needs no refutation. It has been suggested by M. de la Rive that the first germs of hail drop from cirri, or very elevated clouds, charged with positive electricity, and passing through a cloud in which the opposite kind is developed, attract its humidity and thus increase; but every step in this hypothesis is open to objection. The regularity of figure that distinguishes the cirrus seems to be characteristic of clouds perfectly supported and not disposed to fall. But, besides, whatever falls from a great height in the atmosphere must be delicate and minute; and if minute drops fall into a lower cloud they can attract, by virtue of their electricity, only an equal quantity of the other kind, whereas the outer coats of hail far exceed the nucleus.

It is easy to imagine a drop of rain falling from a cloud into a current of very cold air so as to be frozen before it reaches the ground; but this does not explain the phenomena of hail, in which are to be considered the following circumstances:—1, the connexion of hail with electricity, often manifested in thunderstorms; 2, the complex formation of hailstones, which often appear to have passed through several successive processes; 3, their great size, indicating a very sudden and violent precipitation with extraordinary cold. The larger the hailstone, the less likely it is to have fallen from a great height; but the less the height the less also is the time for its solidification and fall. A mass of ice, therefore, as large as a pigeon's egg, formed instantaneously or else while falling from the atmosphere, exhibits an energy, both in the condensation of the fluid and in its prompt congelation, far exceeding what usually comes under our observation.

From experiments made by M. Dufour, of Lausanne, it appears that water in a mixture of almond-oil and chloroform, and of its own density, assumes a spherical figure, and while suspended in that manner may be cooled far below the freezing-point without congealing; but under these circumstances a smart shock of electricity or contact with a particle of ice makes it solidify instantaneously; and the spheroidal mass thus frozen resembles in its structure the ordinary hailstone with a nucleus of white ice and an outer coating of ice-crystals radiating from the centre. Hence it appears that an apparently double structure may be the result of a single process, and take place in a globule frozen from without. It is evident that globules of water floating in the air are in the condition best capable of resisting congelation, and might, as in the experiment just described, undergo their change of state at a very low temperature; but we cannot understand how aqueous globules of the size of ordinary hailstones could be suspended in the air.

The explanations generally offered of the formation of hail are, as Sir J. Herschel remarked, "too absurd to need refutation." In questioning its connexion with electricity, while at the same time he doubts whether hail be not rather the cause than a consequence of a thunderstorm, the same eminent philosopher shows himself bewildered by the difficulty of the problem. He justly remarks, however, that "the generation of hail seems always to depend on some very sudden introduction of an extremely cold current of air into the bosom of a very quiet, nearly saturated mass." The peculiarities of hail which require explanation are :—first, hailstones often or generally exhibit in their structure a twofold structure; they have a nucleus of rough ice or concentric layers, and over this a coating of ice-crystals; secondly, the hail-shower is long and narrow, brief and local.

Now it is generally admitted that thunder always precedes hail; and electricity alone seems capable of accounting for the one thing required for the production of hail—namely, intense and sudden cold. If the action of lightning in the clouds resembles its action on trees in a forest, if it rends the air and repels it with extreme violence in all directions, the result must be a momentary vacuum or a dilatation approaching to a vacuum throughout the whole line of electric action. The immediate effect of that dilatation must be intense cold, the more intense the more rapid the process; and the humidity immediately involved in it will be congealed, but with a speed and violence incompatible with crystallization. Both Sir J. Herschel and M. Arago state that hailstones are due to sudden and intense cold; and whence can this come but from dilatation produced by electricity? Hence the nuclei of the hailstones. The cloud around the area of dilatation will be compressed, and thereby brought to a state of saturation. This abundant moisture is quickly gathered by the intensely cold nuclei, which collect ice in falling as long as they retain excess of cold. Falling faster than liquid drops, they grow larger at the lower end; hence they are often pear-shaped. Strong wind might produce the same effect. Thunderstorms over plains always advance in lines with little breadth. No reason can be assigned for the narrowness of hailstorms, except their dependence on electricity.

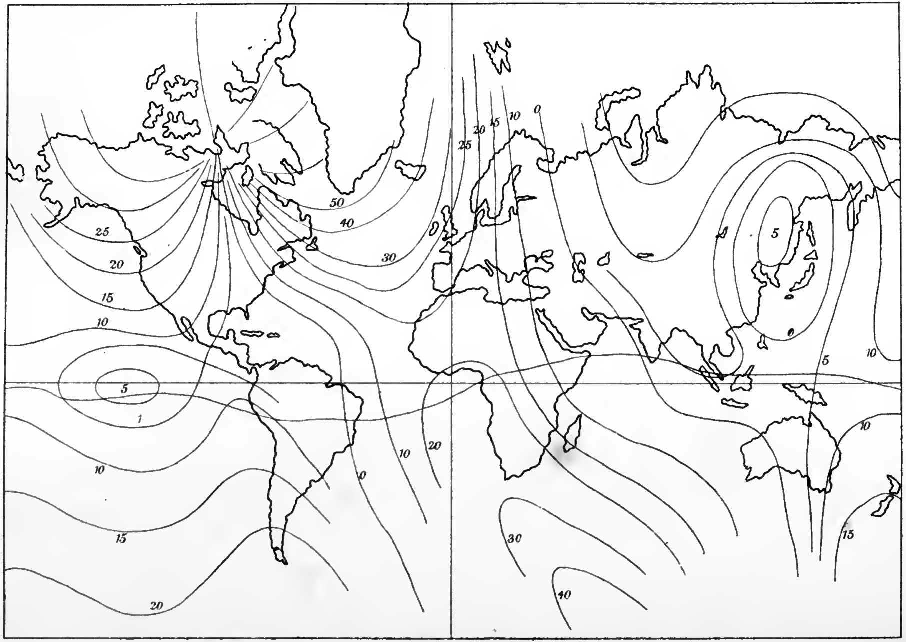
CHAPTER XXVI.

Magnetism.—Properties of the Magnet.—Terrestrial Magnetism.—Declination of the Needle—its History—Variation, Diurnal and Annual.—Inclination or Dip—its Changes—Intensity.—Isogonal, Isoclinal, and Isodynamic Lines.—Magnetic Equator.—Table of Magnetic Elements.—Magnetic Storms.—Theory of Terrestrial Magnetism—Hansteen—Gauss—Ampère.—Power of Magnetism evinced in Basaltic Columns.

Magnetism, or the peculiar property exhibited by the natural magnet (an oxide of iron), or by a magnetized bar of iron or steel, is now recognized as a form or consequence of electricity. A current of electricity passing through a helix or coil of wire insulated throughout will cause deviations in a magnetic needle suspended in the axis of the coil, or will render magnetic a needle of soft iron placed in the same position. Reciprocally a magnet can be made to produce an electric current in a surrounding coil. In magnetism, therefore, we seem to have electricity in a fixed condition or deprived of volatility.

The phenomena of the magnet are as follows :—It attracts iron with a force increasing from the middle of the bar to its extremities, which are its poles. A magnet freely suspended assumes a certain position with respect to the meridian, one pole pointing towards the north the other to the south. If two magnetic needles be brought together, it will be found that the poles of the same denomination (that is, northern or southern) repel each other, while between those of different names there is mutual attraction. The poles of the magnet, therefore, exhibit antagonism, like that of the two electricities, positive and negative. An insulated conductor in which electricity has been developed by induction closely resembles a magnet. If the inducing electricity be positive, that of the conductor will be negative at the end where the induction takes place, and positive at the other extremity.

The peculiar attractive and repulsive powers of the natural magnet (oxide of iron), or of the magnetized iron bar, are not



TERRESTRIAL MAGNETISM. ISOGONALS.

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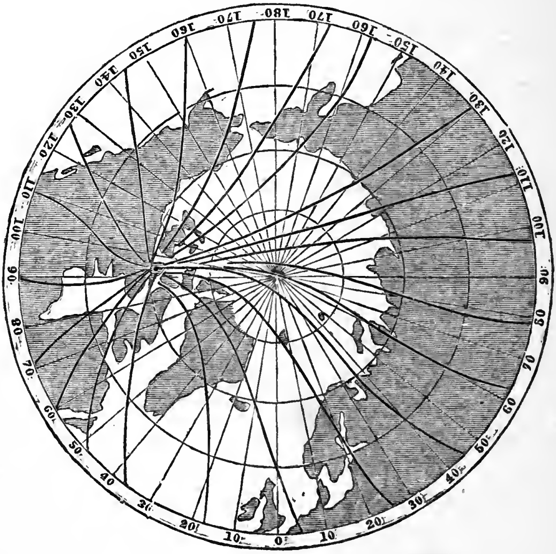
originally inherent in them ; but iron being under certain conditions susceptible of magnetism, takes it from the earth, which is pervaded by it, as the atmosphere by electricity. Terrestrial magnetism, which alone is here to be considered, becomes manifest by its influence on the magnetic needle, varying with time and place over the earth. Consequently a magnet freely suspended assumes, as already stated, a certain position in relation to the earth's axis. This position, or the angle made by the magnet with the meridian at any one place or time, can be learned only by observation. One pole of the needle points towards the north, the other towards the south. There are, however, only two lines on the earth's surface on which it points exactly to the north or south, and where the magnetic and geographical meridians appear to coincide. Elsewhere the needle deviates more or less from the meridian ; and this angle of deviation, commonly called the variation of the compass, but more correctly the declination, varies from place to place, and in the course of time at the same place. (See Plate of Isogonals.)

In 1576 the needle in London pointed to 11° 15 East of North, or that was the amount of eastern declination. Moving westwards, it coincided about 1660 with the meridian, and there was no declination. Still going westwards, however, it reached, in 1814, its maximum western declination (24° 20′), and began again to move eastwards, not regularly but altogether at the rate of about five minutes in a year. The declination at Greenwich is therefore at present 19° 15′ W. The lines of equal declination are also called Isogonal lines, because on them the angles made by the needle with the meridian are all equal. The name magnetic meridians sometimes given to them does not in any degree express their character. They are so irregular in figure, and the laws of their variations are still so imperfectly known, that their positions in successive years cannot be predicted, but must be left to future observation. It is obvious that they all pass through the magnetic poles (fig. 101).

The declination of the needle is subject to daily and annual variations. The diurnal variation was discovered by Graham in 1722. From sunrise till about an hour after noon the north point of the needle moves westwards ; it then returns slowly and resumes its first position about 10 o'clock at night, and there remains unmoved till morning. This variation amounts in the mean in summer to 13 or 15 minutes, in winter to only 5 or 6.

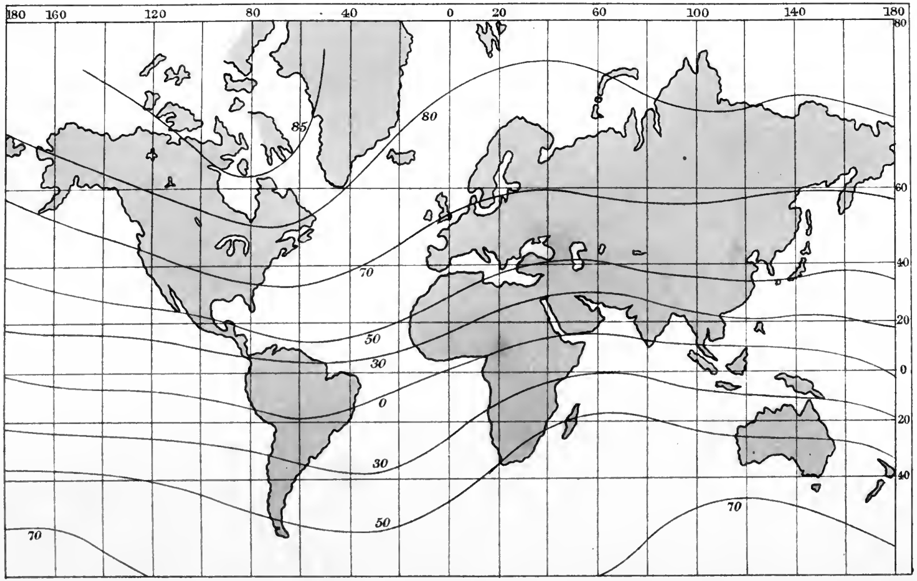
Fig. 101.



Isogonal Lines on the North-polar Projection.

The time of the extreme deviations is not the same everywhere: at Freyberg they occur an hour earlier than at Kasan. In Iceland, and probably all countries near the poles, the diurnal movements of the needle are more regular and strongly marked than elsewhere; near the equator they are feeble though still observable. They are rarely exactly alike on two days in succession. In these variations, most active during daylight, it is easy to recognize the effect of the sun above the horizon.

The annual variation again, being regulated by the equinoxes and solstices, points to the same influence. From January to April the needle recedes from the north pole, and the western declination increases. From April to the beginning of July, or from the vernal equinox to the summer solstice, it decreases. It then goes westward again, but more slowly, till the next vernal equinox, moving eastward for three months and back again in



ISOCLINALS.

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nine. The movement to the west continued, it has been seen, 154 years (from 1660 to 1814); and two centuries at least are likely to elapse before the eastern limits of the needle-excursion can be learned by observation.

When a steel bar or needle nicely balanced in the middle is magnetized, its equipoise is thereby destroyed, and the extremity of it, attracted by the nearer magnetic pole of the earth, points more or less downwards. The angle thus made by it with the horizon is called the Dip or Inclination, and the lines marking equal inclinations are described as Isoclinal lines. They intersect the isogonal lines nearly at right angles, and are often called magnetic parallels, though in truth they are rarely parallel. The dip has been decreasing ever since it was first observed in 1671. It was then 75°, it is now (at Greenwich) 67° 42′, and would seem, from its abating rate of change, to be not far from its minimum.

If a magnetic needle be suspended or supported at the centre of a divided circle, so that it moves freely in the plane of the circle, that again being placed in an isogonal line, the circle will then measure the dip, which will increase towards the magnetic pole, where the needle, it is generally stated, hangs vertically; but that would take place only if the magnetic attraction proceeded from the centre of the earth, which is certainly not the case. The exact determination of the magnetic pole or point of greatest inclination and intensity combined is a problem of great importance. The line of no dip, called by some the magnetic equator, runs round the earth, making an angle of about 12° with the equator, and dividing it unequally.

If the dipping-needle, as the magnet mounted so as to measure the inclination is called, be momentarily moved from its position, when at rest in the plane of equal declination it will oscillate about that position with an activity proportional to the force which calls it back to its place of rest. The rate of oscillation of a needle duly suspended for this purpose varies in the duplicate ratio of the magnetic force, and thus shows the intensity of the latter, which is found to increase from the equator to the poles in the ratio of 5 to 9; but the horizontal intensity, which is that generally observed, varies as the cosine of inclination, and therefore, unlike the vertical intensity, increases from the pole to the equator. Declination, inclination, and intensity, marked out by the isogonal, isoclinal, and isodynamic lines, are the three elements from which we ascertain the distribution of magnetism over the earth's surface.

The line of no dip is close to the line supposed to bisect and be at right angles to the isogonals. They both receive the title of magnetic equator; near them also is the line of least intensity. Materials are wanting for the determination of these lines, but it is certain that they are distinct. The first of these, the line of no dip or inclination, has attracted most observation. It was found by Duperrey in 1828 to lie as follows:—Near the western side of Africa, in about long. 18° E., going westwards, it crossed the equator from N. to S., and reached its greatest distance from that line (14° 20′) in lat. 26° S. It then crossed South America, leaning to the N., and approaching close to the equator a little to the west of the Galápagos Islands. It clung to that line without crossing it; but just touching it in long. 118° W., turned again southwards, and reached lat. 3° 15′ S. in long. 161° W.; it then inclined northwards, and in long. 184° W. it cut the equator nearly in the meridian of the Mulgrave Islands. In the meridian of the Philippine Islands, long. 130° E., it rose to lat. 9° N., and further west near the Gulf of Siam fell to lat. 7° 44′ N. Then again in the Indian Ocean near Eastern Africa it attained its greatest northern latitude, 11° 47′, and thence descended to the equator. Thus it cut this line unequally, about 200° being south of it and 160° to the north. The line of no inclination or magnetic equator, as Duperrey deemed it, has unquestionably undergone since his time changes of position, cutting the equator further west, but no alteration of general character.

Of the lines of no declination or zero-isogonals, one passes through the American continent from N.N.W. to S.S.E., bending in the Northern Atlantic Ocean more to the eastward, and meeting the meridian of Greenwich in about lat. 70° S. The other, on the opposite side of the globe, runs through the White Sea and Eastern Russia, across the Caspian Sea, and close to the Malabar coast, and thence south-eastwards to Western Australia. Further east, in China and Siberia, eastern and western declinations appear so unaccountably intermixed, and scanty materials have given birth to such widely different constructions, that it is utterly impossible to give an intelligible account of the isogonal line in a few pages, or a satisfactory one in a volume. Some idea of them may be formed by the study and comparison of maps of magnetic curves. The isogonals of Eastern Asia, as we find them represented, cannot be reconciled with any theory hitherto proposed as to the seat or cause of magnetic attraction; nor are the changes through which the whole system must pass in the cycle of secular variation yet completely known.

It was discovered by M. Hansteen, the Norwegian philosopher, that magnetic intensity also has its diurnal and annual variations. It generally decreases in the morning till 11 o'clock, and then goes on increasing till 4 o'clock in the afternoon in winter, 6 or 8 o'clock in summer. Its absolute minimum occurs in January, its maximum in July. These results, found in the northern hemisphere, bear further testimony to the influence of the sun. It can hardly be doubted that the Inclination or Dip also has its daily variations, though, being observable only with very delicate apparatus, they have hitherto escaped notice.

Terrestrial magnetism is not confined to the surface of the earth. At the greatest height reached by MM. Biot and Gay de Lussac in 1804 (21,600 feet), they found its intensity little diminished.

The character of the magnetic elements, isogonal, isoclinal, and isodynamic (or, in other words, the declination, the inclination or dip, and the horizontal intensity), may be learned by inspection of the following brief Table[*] :—

	Year.	Declin.	Inclin.	Intensity.
Greenwich	1850	22° 29′·5	68° 48′	1·739
Dublin...............	1845	27 0	69 41	1·689
Paris	1850	20 35·8	66 42·2	1·858
Berlin	1845	16 32	67 35	1·780
Leipzig	1850	15 43·8	67 5	1·831

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[*] The sign *minus* (–) is prefixed in this Table to *Eastern* Declination and *Southern* Inclination.

	Year.	Declin.	Inclin.	Intensity.
Munich	1850	16° 13′·6	65° 24′·9	1·925
Vienna	1850	13 33·5	64 22	1·995
Venice	1845	14 4	64 22	2·036
Milan	1845	17 0	63 13	2·037
Ofen	1845	12 52	63 20	2·036
Hermannstadt......	1845	12 15	67 5	1·831
St. Petersburgh ...	1842	6 21	71 0	1·658
Moscow	......	3 2	68 57	1·762
Christiania	......	19 50	72 7	1·547
Reikiavig...........	......	43 14	77 0	......
Spitzbergen.........	......	25 12	81 11	0·836
Tiflis	1845	1 52	......	2·554
Yakutsk	......	5 50	74 18	1·571
Irkutsk	......	−1 38	......	......
Pekin	......	1 48	54 49	2·925
Singapore	1841	−1 39	−12 1	3·671
Macao	1841	−0 35	30 1	3·428
Cape of Good Hope	1842	29 13	−53 20	2·115
St. Helena	1842	23 32	−21 52	2·734
New York	1840	5 34	72 39	......
Washington.........	1842	1 24	71 14	2·007
Sitka	1845	−28 53	75 51	1·466
Ft. Vancouver......	1839	−19 22	69 22	2·040
San Francisco......	1838	−15 20	62 0	2·526
Bahia	......	4 18	5 24	3·036
Callao	1838	−10 44	− 6 14	3·403
Pernambuco	......	5 54	13 13	......
Rio Janeiro	......	− 2 8	−18 30	......
Valparaiso	......	−15 18	−39 7	......
Sydney	1842	− 9 51	−62 49	2·712
Hobarton...........	1846	− 9 55	−70 36	2·070

With periodical variations, diurnal, annual, and secular, terrestrial magnetism is liable also to sudden and irregular disturbances, which become at times so violent as to be appropriately styled Magnetic Storms. The needle on such occasions becomes restless, trembles constantly, oscillates widely, and becomes deflected from 2° to 6° from its ordinary position. What is most remarkable in these phenomena is the immense area over which they are simultaneously manifested. Perhaps it may be boldly asserted that they extend at once over the whole earth. The magnetic storms observed at Toronto in Canada have been found to be simultaneous with those of Hobarton, Tasmania. It has been ascertained also that the needle is disturbed whenever the phenomena of Aurora Polaris are visible ; whence all disturbances may be easily explained, since it can hardly be doubted that auroral phenomena are always observable at one or the other pole.

The theory which first offers itself for the explanation of terrestrial magnetism is that the earth itself is a magnet, the axis of which does not coincide with the axis of revolution, and therefore the magnetic poles are at some distance from those in which the geographical meridians unite. But it was demonstrated by M. Biot, from a careful analysis of observations, that the poles of the hypothetical magnet cannot be near the earth's surface, and that in order to reconcile or reduce to one system the magnetical phenomena of the globe, it is necessary to assume that the poles or attracting points are near the centre and not far asunder. On the other hand, great heat and magnetic development are found to be incompatible ; consequently it cannot be supposed that any magnetic force really emanates from the deep interior of the globe or the vicinity of its centre. The hypothetical magnet within the earth is therefore a mere speculative phantom ; and it must be assumed that terrestrial magnetism is generated on the earth's surface, in obedience to laws which, owing to the sphericity of that surface, refer it more or less entirely to the centre.

Nevertheless M. Hansteen, who devoted his life to the study of terrestrial magnetism, ventured to conclude that all its phenomena may be accounted for by the supposition of two magnets within the earth and prolonged to the surface, thus forming two magnetic poles, a stronger and weaker, in each hemisphere. These poles revolve, according to him,

The Northern Strong pole in 1890 years,
The Southern Strong pole in 4605 „
The Northern Weak pole in 860 „
The Southern Weak pole in 1303 „

The position of the poles were, in 1810 :—

	Lat. N.	Long. W.		Lat. S.	Long. E.
Strong N. P.	69° 45′	91° 28′	Strong S. P.	68° 59′	133° 21′
Weak N. P.	85 18	135 54	Weak S. P.	78 3	133 14

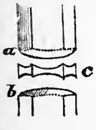
But all these calculations, though the fruit of persevering labour, evidently rested on no better foundation than hypotheses accommodated as much as possible to the explanation of phenomena, and recommended solely by their convenience. Hansteen's doctrine, therefore, was destined to give way to any mode of explanation which, relying on physical laws as known on the earth's surface, could dispense with internal magnets and underground machinery. It yielded, therefore, to the theory of Gauss, which had the advantage of simplicity, admitting only two magnetic poles ; and yet, since it allows the existence in the northern hemisphere of two points of maximum intensity, its simplicity seems more verbal than real.

Since magnetism may be but a mode of electricity, and electricity is continually active in and above the surface of the earth, it was natural to look to the latter for the source of terrestrial magnetism. Hence M. Ampère, distinguished by his remarkable discoveries in electricity, maintained that magnetism is the result of electric currents passing round the globe from east to west ; and his opinion prevailed for a time, being adopted by philosophers of great eminence. He ascribed its variations to fluctuations in those currents due to changes of temperature. This theory offers no explanation, either of the singular unsymmetrical distribution of magnetism over the globe, or of its periodical changes. There are others, again, who believe terrestrial magnetism to be derived directly from the sun. Its periods of variation, diurnal and annual, are obviously regulated by solar time, and its disturbances (the magnetic storms) seem to be connected with the solar spots, both phenomena recurring in greatest frequency at intervals of 11·11 years. The sun figures in this theory as a powerful magnet, while the earth takes the place of the soft iron, in which magnetism is induced. The moon, too, by reacting on the earth, has its share in the diurnal variations of the needle. In short, the phenomena of terrestrial magnetism are extremely complicated, proceeding from several different forces, acting independently, with various laws. Direct, induced, and reflected forces are blended together, while incidental electric currents interfere to disturb the results and make all uncertain.

Magnetism, it is well known, is communicable by attrition and other means to bodies capable of receiving it. The loadstone or natural magnet is an iron-ore which has received its magnetism from the earth. In its presence, or in contact with it, a bar of soft iron becomes magnetic ; a bar of steel not only receives the magnetism, but retains it. That the loadstone owes its magnetic properties to the earth is very evident. A bar of iron placed in the magnetic meridian, with the inclination of the dipping-needle, will become in a short time magnetic. Hence it is not surprising that basaltic columns (such as those at the Giant's Causeway) containing a large proportion of iron, and sloping to the north in a position which may at one time have coincided with the declination and inclination of terrestrial magnetism, should be highly magnetic.

But it seems to have escaped observation that magnetism may possibly have had some share in the formation of those columns, or the metamorphosis, as it may be called, of the basalt. If we suppose the basalt, when first solidified and cooling, to have been acted on by some cohesive principle perpendicular to the surface, this would tend to separate the mass into prisms, and, the mass being uniform throughout, into equal prisms or circular columns pressed close together—that is to say, into hexagonal columns. These columns would resemble to some extent bars of iron. Again, they are divided into joints, which are supposed to be united by what is called articulation, the convex extremity of one joint being inserted into the concave end of the succeeding joint, and these concave and convex faces being, as the matter is generally represented, turned irregularly up or down. But this mode of representing the so-called articulation is totally erroneous. The truth is, that the joint of the basaltic column is convex at both ends (*a* and *b*, fig. 102) ; the portion *c*, therefore, that

Fig. 102.



binds the joints together is a double concave; and according as this loses its hold above or below, the joint broken off is convex or concave.

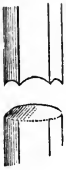


Fig. 103.

Now if a well-proportioned magnet (M N, fig. 103) be carefully examined, it will be found that its pole or maximum power is not at its extremity, but a little further in at *a*, and that it retires from the angles, so as to form a convex line (*b a c*) within and towards the end of the magnet. Again, a disproportioned magnet or very long bar (fig. 104) will be found to be in reality a series of magnets, with separate neutral points and poles, the latter increasing in strength towards the extremities of the bar. Thus it appears that the division of the basaltic column (fig. 105) closely resembles that which might be produced by magnetism, supposing that this could, in the course of time, effect a change in the cohesion of surfaces. It may be added that the texture of the basalt between the joints differs from the rest, so that its outlines on the two joints which it connects can be almost always traced by a practiced eye.

Fig. 104.

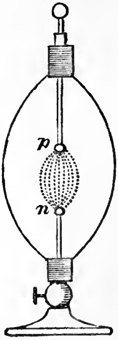
Fig. 105

CHAPTER XXVII.

Aurora Polaris.—Interchange of Electricity between the Pole and Equator.—M. de la Rive's Theory.—The Electric Brush.—Phenomena of Aurora described—rarely complete.—Cosmical Origin of Aurora disproved.—Prof. Olmsted's views.—Phenomena widely visible not therefore Cosmical.—Aurora not equally visible from all sides—its great Velocity—an Optical Phenomenon—Zone of its frequent Appearance.

A CIRCULATION of electricity takes place between the equator and the poles, the interchange of their electricities thus effected between the atmosphere and the ground reuniting the accumulations on both sides and restoring equilibrium. It has been pointed out by M. de la Rive that the redundant positive electricity of the equatorial atmosphere arising from the ocean is borne by aerial currents to the poles, and there exhibits on a great scale the phenomena that draw attention to the experiment of the electric egg. Let a glass vessel of oval shape, and tubular at both ends, be fitted with brass rods terminating within in small balls, the upper one moving in a collar of leather, the lower one communicating with the ground and fixed in the tube, which must be so framed as to admit of being connected with an air-pump (fig. 106). Now the brass balls being a few inches asunder, whenever a charge from an electric machine passes to the upper brass rod, a spark will at the same instant pass from the upper to the lower ball; but if the air in the glass ball be partially withdrawn, the sparks divide into threads of purplish-coloured light curved outwards in the middle, so as to form an oval figure ($p\ n$). If the exhaustion of the air be carried further the light becomes more diffused, varying in brilliancy and colour with the distance between the balls and the strength of the electricity. The jets of light are always most brilliant at the top near the positive electricity, with a colour inclining to purple. The

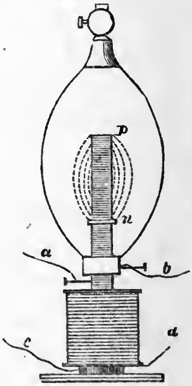
Fig. 106.



base of the egg has a violet hue, and is separated from the brass ball by a black line.

But if the brass rods be removed, and instead of them a magnetized bar connected from below with the electric machine be placed in the exhausted vessel, the electric egg will be more completely developed from the edges of the magnet, round which it will revolve, its colours varying, as in the preceding case, with the degree of exhaustion and other circumstances (fig. 107). A large share of the gorgeous display seen in the aurora is due to clouds and vapours rendered luminous by electricity; but the jets of light shot up towards the zenith owe their colours to the tenuity of the air in the upper regions of the atmosphere.

Fig. 107.



The phenomena of the aurora polaris, in their general and essential outlines, have been described by A. von Humboldt in the following words:—"Low down on the horizon, about the part where it is intersected by the magnetic meridian, the sky, which was previously clear, is darkened by an appearance resembling a dense bank or haze, which gradually rises and attains a height of 8 or 10 degrees. The colour of the dark segment passes into brown or violet, and stars are visible through it as in a part of the sky obscured by thick smoke. A broad luminous arch, first white, then yellow, bounds the dark segment; but as the bright arch does not appear till after the segment, Argelander is of opinion that the darkness of the latter cannot be attributed to the mere effect of contrast. The azimuth of the highest point of the luminous arch, when carefully measured, has been usually found not quite in the magnetic meridian, but from five to eighteen degrees from it, on the side towards which the magnetic declination of the place is directed. In high northern latitudes, in the near vicinity of the magnetic pole, the dark segment appears less dark, and sometimes is not seen at all; and in the same localities, where the horizontal magnetic force is weakest, the middle of the luminous arch deviates most widely from the magnetic meridian. The luminous arch undergoes frequent fluctuations of form; it remains sometimes for hours before rays and streamers are seen to shoot from it and rise to the zenith. The more intense the discharges of the aurora, the more vivid is the play of colours, from violet and bluish white, through all gradations to green and crimson. In the common electricity excited by friction, it is also found that the spark becomes coloured only where a violent explosion follows high tension. At one moment the magnetic streamers rise singly, and are even interspersed with dark rays resembling dense smoke; at another they shoot upwards simultaneously from many and opposite points of the horizon, and unite in a quivering sea of flame, the splendour of which no description can reach, for every instant its bright waves assume new forms. The intensity of this light is sometimes so great, that Lowenorn (in January 1786) discerned its coruscations in bright sunshine. Motion increases the visibility of the phenomenon. The rays finally cluster round the point in the sky corresponding to the direction of the dipping-needle, and there form what is called the corona. When this takes place the display terminates. The streamers now become fewer, shorter, and less intensely coloured; the corona and the luminous arches break up, and soon nothing is seen but irregularly scattered, broad, pale, shining patches of an ash-grey colour; and even these vanish before the trace of the original dark segment has disappeared from the horizon. The last that remains of the whole spectacle is often merely a white delicate cloud, feathered at the edges, or broken up into small round masses like cirro-cumuli."

To this account of the aurora it only needs to be added that the corona which completes the spectacle is very rarely seen at a distance from the magnetic pole. The natives of north-polar regions all state that the coruscations of the aurora are attended with a rustling sound; and European scientific inquirers have in almost every instance given credit to the testimony of the natives, though they have not themselves heard the sound in question. Von Wrangell, indeed, acknowledges that he did hear "a slight hissing sound as when the wind blows on a flame." The allusion to Lowenorn calls to mind the fact that

Dr. Henry Usher observed in Ireland, in May 1778, an aurora in broad daylight, and that his observation was found by Arago to be confirmed by the records of magnetical disturbance in the Observatory at Paris.

The cosmical nature ascribed by some to the aurora was fully disproved by Biot, when he observed at the Shetland Islands that the auroral arch did not revolve with the stars. That a cosmical phenomenon taking place beyond the earth's atmosphere should be attached to a particular point of the earth's surface, and constant during its appearance on a particular meridian, is highly improbable. But there is abundant testimony to prove that the aurora is often no higher than the clouds, and may descend to the surface of the earth. Dr. Richardson, Captains Parry, Back, and Hood, and Von Wrangell, nearly all, indeed, who have had opportunities of constantly observing the aurora, suppose it to have but a moderate elevation in the atmosphere. Gisler walked through it on the Norwegian highlands, and felt the electricity on his face. It is certain that the elevated haze and clouds (cirri) take a part in its display—that, in short, the more stedfast portion of the auroral spectacle, the arch of light, is formed of cloud or haze rendered luminous by the electricity; and it has been frequently observed that the clouds retain for some time after an aurora the figure or arrangement given them by the electric influence. Thus Von Wrangell says that the streamers resolve themselves into luminous patches, "which frequently continue to be visible on the following day in the shape of white wave-like clouds." And, again, he remarks, "The aurora does not always occupy the higher regions of the atmosphere; it is usually nearer the surface of the earth; and this is shown by the visible influence of the lower current of the atmosphere in the beams of the aurora. We have frequently seen the effect of the wind on the streamers as obvious as it is on the clouds; and it is almost always the wind which is blowing at the surface of the earth."

M. de la Rive's theory has not met with universal acceptance. Professor Denison Olmsted, in the United States, maintains that the aurora (to the phenomena of which he has paid much attention) is cosmical or beyond the earth's atmosphere, and not in its cause connected with the earth. These conclusions he founds, first, on the great extent of the phenomenon. The aurora of November 1848 was visible everywhere from Smyrna westwards to San Francisco, on the shores of the Pacific Ocean; and he thinks it unlikely that a merely atmospheric phenomenon should extend round nearly half of the globe; but the height to which he would elevate it (160 miles) could avail little to remove this difficulty.

And, indeed, we do not understand how the improbability supposed to attach to the great extent of the phenomenon is diminished by removing the ring of light on the arch further from its apparent centre, and thus increasing its extension. Probability seems to have been in this instance arbitrarily calculated, in accordance with the desire to expel the phenomenon from within the atmosphere. Since hailstorms, rarely extending beyond five miles and falling from a moderate height, have been known to extend in a few hours over a thousand miles, we can have no difficulty in believing that an electric disturbance may embrace 10,000 miles. A phenomenon visible 160 miles from the earth may be naturally supposed to be an emanation from the earth. Certainly, if its character is to be determined by a comparison of its distances from the earth and from the heavens, it must be called terrestrial and not cosmical.

Secondly, aurora is often visible at the same hour at places differing widely in longitude, as London and New York; the phenomenon must be supposed therefore either to travel westwards in the atmosphere at the rate of the earth's rotation, or to be fixed in position outside the atmosphere; and the latter is the alternative preferred by Prof. Olmsted. He does not perceive that the assumption which seems to remove difficulty in some few cases, creates it in many more; for were the aurora a substantial reality and cosmical fixture, it ought, when visible at any place, to be visible everywhere on the same parallel at least. But supposing it to be within the atmosphere and a consequence of atmospheric electricity, the fact that it is everywhere most conspicuous two hours before and two hours after midnight, appears to us to be the natural law, not so much of the existence of the aurora as of its visibility. It is visible at the same time at places widely apart in longitude; but we learn that the arch of the aurora is found to be a portion of a small circle parallel to the earth's surface; it may therefore be part of a ring round the earth's axis. If a luminous ring were formed round the earth near the pole, it would be visible from all longitudes; all would see a similar part of the same auroral ring.

Thirdly, its velocity is too great for terrestrial matter, and not sufficient for electricity. But what is the velocity here spoken of but that of the luminous waves streaming upwards? If the well-excited cylinder of an electrical machine be pressed with a dry hand, streams of blue light will issue from it, analogous to the streamers of the aurora. Their velocity is not that of electricity, but of the electrical excitement whose propagation they mark. The velocity of one electricity accumulating is not to be confounded with that of the recombination of electricities—that is, with the electric current.

Fourthly, we are told that the periodicity of the aurora proves its cosmical nature; but its periodicity is at present merely conjectural: we only know that its occurrence is irregular; and that irregularity is the characteristic of atmospheric phenomena, most of which are at the same time periodical. We know also that its periodicity would seem to connect it with the magnetism of the earth, which is terrestrial under cosmical influence.

The frequency of aurora borealis does not depend on distance from the north pole; it evidently increases in the direction of the American continent, as if the phenomenon emanated from the magnetic pole discovered by Sir J. Ross, in lat. 70° 5′ N., long. 99° 12′ W., to the north-west of Hudson's Bay. It is seen, we are told, in Havana about six times in a century. This number, as we go northwards, increases at the 40th parallel to 10, at the 42nd to 20 a year; in lat. 45° it becomes 40, in lat. 50° 80 annually. In lat. 62°, near Hudson's Strait, auroras are seen almost every night, and often to the south. Further north they appear generally to the south, declining in frequency and complete development towards the north pole. In lat. 78°, near Smith's Strait, the spectacle of the aurora occurs only about ten times in a year. In the meridian of St. Petersburgh the zone of eighty auroras begins not at the 50th but at the 66th, and continues to the 75th parallel. At Point Barrow, in lat. 74°, on the northern coast of America, aurora was seen by Captain M'Clintock once for every three nights of observation, and would be visible, it was thought, every night if not concealed by stormy skies. From that point, a little further north than the magnetic pole, it was always seen in the south. Surely the unequal and locally partial distribution of the aurora on the earth tend to prove that it is not a cosmical phenomenon.

The cosmical theory of Professor Olmsted seems to rely too much on the assumption that the aurora is in substance and position a real and not a merely optical object, and on the fallacious observations of parallax, which seem to prove its great height. A man may ride a few miles, and have all the time a rainbow within a hundred yards of him on one side. He calls it the same rainbow; but as it has continually changed place with his movements, being an arch of which his eye is the centre, it evidently had only optical existence. Now in the case of an aurora every one sees the summit of the arch near his own magnetical meridian; and consequently observers on different magnetical meridians look at different objects, or rather see the same figure in different places. But, besides, let it be considered that the line which definitely limits the upper edge of a fog bank is only optically real, and undergoes no change of latitude as we approach or retire from it, so the margin of a faintly illumined cloud owes its distinctness to a certain amount of density depending on the visual angle under which it is seen; and consequently the whole arch of the aurora probably changes place with the spectator. If the definition of the figure depends in any degree on the visual angle, the effect must be to diminish the apparent parallax, and to make the phenomenon appear more distant than it really is.

The aurora, though generally known as only an occasional appearance, is probably the wide manifestation of a phenomenon which rarely ceases, though not extensively visible, either from want of intensity or because screened by the state of the atmosphere. At Toronto in Canada it has been observed 261 nights in the year; and those who have had most opportunity of observing it are also most inclined to believe it perpetual.

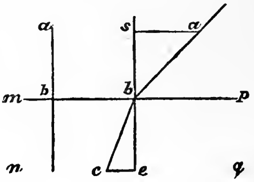
However deficient may be the theory which refers the aurora to atmospheric electricity and terrestrial magnetism, it has the merit of seeking to explain phenomena by known physical agencies, and tracing their apparent subjection to known laws; whereas the nebulous matter or ferruginous vapour supposed by Professor Olmsted to fill planetary space, to produce the zodiacal light, to visit the earth in the form of falling stars, or standing still to appear occasionally as aurora, is so little known, so eccentric and lawless, that it ought not to be resorted to by philosophers except as a last resource.

CHAPTER XXVIII.

Light, its Refraction—Dispersion.—The operation of these in a drop of Rain —with one Reflection or two.—The Rainbow—why circular—disposal of the Colours—Angular Limits.—The Rainbow a mere vision only optically existing—varies in Magnitude inversely as the Sun's Altitude.—Refraction in the Atmosphere.—Incurvation of Rays of Light.—Objects raised by Refraction.—Incurvation inverted by great Heat.—Mirage.—Travellers' Descriptions.

Among the phenomena of light, those alone that arise from refraction need to be here considered. When a ray of light (*a b*, fig. 108) passes from one medium into another (*m n p q*) of different density or refractive power, in a course perpendicular to the surface of the new medium, it continues its course unaltered; but if it meet that surface obliquely, it is then more or less deflected, the refracted ray *b c* approaching or retiring from *s e* the perpendicular to the common surface of the two media according as the medium entered is more or less dense than that preceding it. The refractive power varies in different bodies; but in all cases the ratio of the sine of the angle of incidence *s a* to the sine of the angle of refraction *c e* is constant under every variation of obliquity.

Fig. 108.



The ray of light which has been thus deflected by refraction has this peculiarity, that it is no longer a single straight line, but becomes conical by dispersion (*a b c*, fig. 109); for solar light is in truth compounded of rays of different quality, producing the sensations of various colours and differing also in refractive capability; they may consequently be separated by refraction, and made to diverge.

Fig. 109.

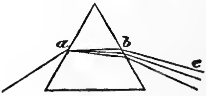


Fig. 110.

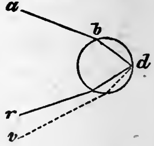
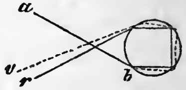


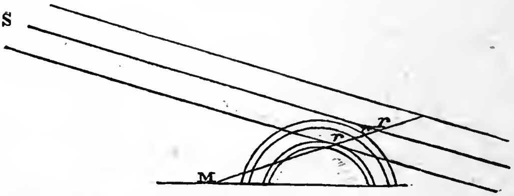
Fig. 111.



A ray of solar light (*a b*, fig. 110) falling on a drop of water may at a certain angle of incidence enter it refracted towards the interior, and then, being reflected from the back of the drop *d*, escape from the front with an inflection similar to that undergone on entering. The ray enters at a single point, then, dispersing after refraction, its components are reflected from different points, and, still diverging, issue from the drop more widely apart. The red rays (*r*) are the most refracted, then follow the orange, yellow, green, blue, indigo, and violet. But the solar ray may also enter the drop with such an incidence that it cannot emerge from it without two reflections (fig. 111). In this case the incident and emergent rays cross each other, and the order of the colours is consequently inverted. Now if instead of considering a single drop of water under the action of the sun's rays, we picture to ourselves an infinite number of drops in a falling cloud or shower of rain, we arrive at once at the explanation of the rainbow.

A spectator, M (fig. 112), with his back to the sun and facing the curtain of falling rain, is in a position to see the coloured light reflected from the latter. The rays of the sun, on account of its great distance, may be assumed to fall parallel on all parts of the cloud; and if a line M *r* from the spectator's eye to the cloud, making a constant angle with the solar ray, be moved round the scene in front it will describe a portion of a circle, the centre of which lies in the plane that connects the spectator with the sun; but the coloured light from the rain-drops is in every case strictly confined to the circular line marked by that con-

Fig. 112.

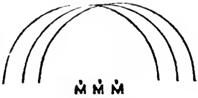


stant angle. The red rays, the most refracted, issuing from the cloud make an angle of 42° 2′ with the incident solar rays; consequently the spectator sees them forming an arch at a height depending on the sun's altitude. The violet and least refracted rays issue at an angle with the incident rays of 40° 17′; these are the lowest as the red are the highest in the primary rainbow; the other colours lie intermediate between these two. Thus the rainbow formed with a single reflection, which is the more frequent and vivid, has a breadth of 1° 45′.

The rainbow of two reflections is much less brilliant than the preceding, because repeated reflection is a repeated loss of light; its light is also curtailed in the first instance by oblique incidence. The violet rays are here uppermost, and make an angle with the incident solar rays of 54° 9′, that of the red rays being 50° 59′; this bow, therefore, has a breadth of 3° 10′. The distance between the primary and secondary bows is 8° 7′.

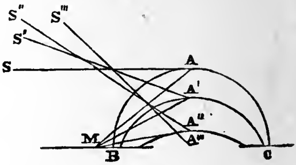
Let it be observed that the spectator, though not in the centre of the rainbow, stands in its axis connected with its centre. When a number of persons therefore, M M M (fig. 113), look together at a rainbow, they may suppose that they all see the same object; but, in fact, each individual sees his own bow, and stands before its centre. Then, as the sun's rays are all parallel, the line drawn to them from the spectator cuts them at all distances (*r r r*, fig. 112) at the same angle. Consequently each coloured light proceeds not from a single plane or distance, but is collected from all distances in the same direction. Thus the rainbow has only an optical existence, its place depending on that of the spectator.

Fig. 113.



It is obvious that the greater the sun's altitude, the lower must be the rainbow. An angle of 42° 2′ must always separate the solar rays from the line of vision (fig. 114) directed to the red or upper edge of the primary bow. The latter line reaches its greatest elevation when the sun's rays, S A, are horizontal, or when the luminary is rising or setting. At sunrise or sunset, therefore, the rainbow may appear as a semicircle (B A C, fig. 114) with a diameter of 84°; but as the sun rises above the horizon to S' or S'' the coloured bow must descend to A' or A'' ; and when the sun attains at S''' the altitude of 42° 2′ the primary bow sinks in the horizon. At midsummer, therefore, in lat. 52° N., when the sun rises to an altitude of 61°, there can be no primary rainbow during nearly 3 hours about noontide.

Fig. 114.



If we suppose a ray of light (a b, fig. 115) to fall obliquely on a series of transparent and horizontal strata, increasing in density downwards, it will be deflected more and more towards the vertical line as it descends through them ; and if instead of successive strata we suppose one medium continually increasing in density downwards (fig. 116), the refracted ray c b will be no longer a crooked line with a succession of angular joints, but a curve or line of continuous inflection. Now the atmosphere is such a medium as that here described, growing continually denser towards the earth's surface, and every ray of light which does not come from the zenith must strike on it more or less obliquely. A ray of light, therefore, passing through the atmosphere describes in general a curve (a b), the convexity of which is upwards (fig. 117) ; and the object b' being seen in the direction of the ray that meets the eye at a, its apparent place is higher than its real place, or, in other words, it is raised by ordinary refraction. This displacement necessarily increases with the obliquity of the incident ray ; it disappears totally at the altitude of 90° or in the zenith, is inconsiderable down to 45°, and thence increases rapidly till at the horizon it has a mean amount of about 33 minutes ; so that when we see the sun with a diameter of about 32 minutes, just

Fig. 115.

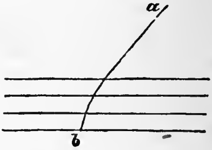


Fig. 116.

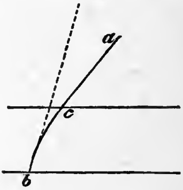
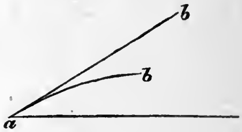


Fig. 117.



touching the ocean with its lower limb, it is in reality entirely below the horizon.

The variations of refraction depending on temperature and the state of the atmosphere have a range of more than two degrees, and, by displacing the visible horizon, throw much uncertainty on observations of altitude. This inconvenience is generally found by seamen to accompany extremes of temperature. In the polar seas the cold on and about the ice greatly increases the refraction, particularly if a warm wind from lower latitudes prevails above. Within the tropics refraction varies with the opposite characters of the land- and sea-winds, and at times increases so as to bring within the visible horizon an almost incredible distance. An instance occurred, and occasioned much discussion in nautical circles, some years ago of a pilot in Mauritius descrying a vessel at a distance of 200 miles; and, strange as this may appear, a well-authenticated instance of the same kind subsequently occurred at Aden. A pilot at the latter place announced that he had seen from the heights the Bombay packet then nearly due. He stated precisely the direction in which he saw her, and added (what seemed a remarkable circumstance) that her head was not turned towards the port. This caused some alarm, and a steamer lying in the harbour was sent out to meet the packet supposed to be disabled; but it cruised about for a whole day in the indicated direction to no purpose. In a couple of days, however, the packet entered the port, and it was then found that at the time when she was announced by the pilot, she was exactly in the direction and position described by him, but 200 miles off. In this case the curvature of the visual ray due to refraction was equal to that of the earth's surface. In temperate climates the variation of refraction, though confined within moderate limits, is yet capable of producing very remarkable effects. Snowdon is said to be now and then visible to the pilots in the Bay of Dublin. Two or three times in a century the Isle of Wight may be seen from Brighton; in 1829 it rose to view completely above the waves so as to be visible to its very base; the coast of France could at the same time be traced as far south perhaps as Dieppe. The same spectacle reappeared in 1855.

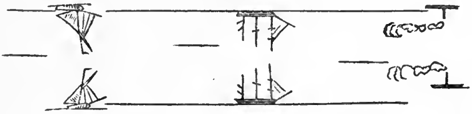
Ordinary refraction in the atmosphere is a consequence of the density of the air continually increasing downwards. The rays of light are incurvated by it, so as to turn their convexity upwards; and as the object is seen in the direction of the ray which enters the eye, it is raised by ordinary refraction above its true place. But in opposite circumstances, or when the denser air is above and the more rarefied below, there may be irregular or extraordinary refraction, which, bending the ray so as to make it convex downwards, depresses the object. When strata of air of unequal densities are irregularly intermixed, it frequently happens that groups of rays from the same object are not uniformly inflected, but vary in curvature according to their height above the ground, and cross each other before they reach the eye. The consequence of this is that the object is seen inverted. But there is nothing to prevent the eye seeing at once an object upright through uniform strata of the atmosphere and inverted and misplaced by irregular refraction.

If an iron bar or a board of moderate length, blackened, be exposed to the sun's rays, it will soon become heated, and will radiate the heat in such a manner as to rarefy the air near its surface, the rarity diminishing rapidly till at a little distance from it the air resumes its ordinary and uniform density. Now an eye suitably placed, and looking along the heated surface of the bar or board, may see an object directly through the uniform stratum of air, and also at the same time see an inverted image of the same object by means of rays refracted through the unequally rarefied strata. It is obvious that the refraction will grow stronger towards the heated surface, and that the lowest rays will be the most incurvated. Consequently some rays from the upper part of the object, with a more descending course, will cross the less incurvated rays from its lower part, thus forming an inverted image.

The phenomena of inverted and double images may also be exhibited on a small scale and within doors by an easy experiment. Let a glass vessel be filled one third with sulphuric acid, another third with water poured very gently by means of blotting-paper on the acid, and the remainder with spirits of wine placed by the same means gently on the water. These three fluids will gradually mingle at their surfaces; but for some time they will remain so distinct as to present collectively a transparent medium, increasing rapidly in density from the surface downwards. If, now, a slip of paper with figures on it be affixed to the glass at the back, the eye on a level with the paper will see the figures upright, and at a certain distance will also see them inverted above the upright image, the rarefied medium which inverts the image being in that case uppermost.

At sea a cool breeze beneath a heated atmosphere may cause a rapid change of density in the air near the surface, or, owing to the alternate play of land- and sea-winds, strata of air of different densities may be thrown together and remain for a time not intimately intermixed. In such cases "looming" ensues (an expression derived from the Italian "*lume*," light), or extraordinary refraction with inverted and double images. Indeed it is not unusual in looming to see two or three different horizons at a little distance apart, with images alternately upright and inverted. When this takes place the sky has usually a peculiar leaden hue, which confounds it with the sea, and numerous parallel streaks in it seem as if endeavouring to mark the imperfectly defined horizon. If those images be numerous and close together (which is most likely to occur in straits between bold coasts, where cold and hot winds blow alternately), the repetition of the same figures in the vertical direction will produce a kind of symmetry, in which imagination may easily find a resemblance to architecture. Such, probably, is the nature of the phenomenon peculiar to the Straits of Messina, and called the "Fata Morgana," the accounts of which, however, are probably not free from exaggeration and popular fiction.

Fig. 118.



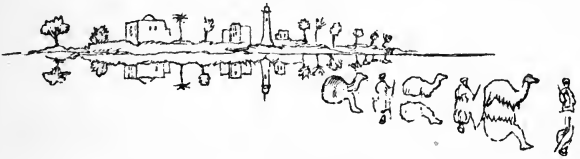
When the irregular refraction, which at sea is attended with what seamen call looming, takes place on land, it produces the phenomenon known as mirage. When a sandy plain or tract of bare ground is intensely heated by a burning sun, the air immediately over it becomes, contrary to the general law, most rarefied where it is in contact with the ground, and increases in density for some distance upwards. An object a little elevated—as, for instance, a palm-tree (P, fig. 119)—may be seen in its true place and position through a uniform stratum of the atmosphere at the level of the eye (A), while other rays passing near the heated ground and bent upward bring to the eye at the same time its inverted image (P′); for the lower rays being the most refracted cross the upper rays, and thus invert the image, just as reflection from a mirror or from a sheet of water would do. The inverted palm-tree appears to be a reflection of that seen upright. The singular characteristic of mirage is this, that in the condition of the atmosphere producing it the low or level ground at a certain distance becomes invisible. Rays of light are incurvated in their passage through the rarefied air near the ground, with their convexity downwards. Suppose H A (fig. 120) to be a ray touching the ground at *m* in the plain B C, it is evident that an eye at A will see the point *m*, and beyond that H, which, being a descending line, may come from the sky; but from the ground beyond *m* and below H *m* no ray inflected in the manner of H *m* A can reach the eye at A. The spectator may see directly through an upper stratum a village above the line *m* H, and also along this latter line an apparent reflection of the village; he may see a caravan visible above the same line and reflected just below it, but the ground beneath *m* H cannot be seen (fig. 121). With the village is also reflected the background of the picture; and that background is the sky, the repetition of which, extending to *m*, or the limit of the visible plain, is mistaken for water. Ordinary refraction raises the visible horizon; the

Fig. 119.

Fig. 120.

irregular refraction that attends looming, on the contrary, tends to depress it.

Fig. 121.



Here it is necessary to remark that descriptions of mirage are rarely faithful. Travellers, not content with the result of actual observation, incautiously draw on their understandings for the particulars of the phenomena, of the nature of which they really know nothing, and thus deck them out with impossibilities. Take the following example from the work of a missionary traveller :—

"The tantalizing sareb or mirage which had mocked our sight since we entered this arid region increased with the power of the sun and the refraction of his rays. . . . . . This treacherous phenomenon deludes the traveller's eye with a regular succession of beautiful lakes and shady avenues ; and then again with an expanse of waving grass around a picturesque villa ; here is presented a grove of towering trees, there a flock of browsing cattle," &c. From the explanation of mirage given above, it will be evident that it creates absolutely nothing. It merely effaces part of the scene and covers the blank with inverted images of objects that rise above a certain level (if there be any such in view) and of the sky above them. This last is mistaken for water. As to the shady groves, picturesque villas, the grass and cattle, they are delusions of imagination, unknown to and incompatible with mirage. But it is not surprising that travellers make such mistakes, when a popular work on Physical Geography, frequently reedited, informs us that "mirage, or the delusive appearances of water, is owing to the reflection of light between two strata of air"—an account of the phenomenon which has no discoverable meaning. A reflection of light implies some visible object reflected. What is that object?

Mirage may be seen nearly every day in summer in the plains of Lower Egypt; and those who have often witnessed it will testify that beauty, brilliancy, and seductiveness are totally absent from it. Objects reflected from the surface of water acquire a softer tint, a less decided outline, and are modified in figure and vividness by the undulation of the reflecting medium. But the inverted figures in mirage add no variety to the picture ; they are as strongly marked and as warmly coloured as those of which they seem to be reflections ; and so long as the denser strata of the atmosphere are overhead, the light that penetrates to the surface of the earth has a lurid hue.

CHAPTER XXIX.

Past Changes of Climate on the Earth.—The Eccentricity of the Earth's Orbit—Effects of its Variability.—Precession of the Equinoxes.—Table of Successive Eccentricities.—The Glacial Period.—The Polar Snow-cap.—Oscillation of the Ocean — Hypotheses weighed — Disordered Calculations.—Uniformity in the Course of Nature.—Change in the Atmosphere—its Effect on Animal Forms.

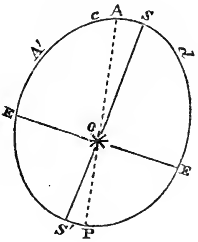
An interesting and perplexing problem, intimately connected with terrestrial physics, has been of late years brought prominently forward by palæontological researches. From fossil remains of plants and animals it may be concluded that countries situate far within the polar circle must once have enjoyed a temperate or even a warm climate. Not merely scattered trees but vestiges of forests, chiefly of a species of pine, have been discovered on the islands of the polar sea north of the American continent, up to lat. 76° N.; and heaps of similar buried stems of pine-trees are found in the frozen soil on the northern shores of Siberia. On the other hand, traces of the former predominance of glacier-ice may be detected in comparatively low latitudes. How are we to account for such changes in the climate of the globe? The explanations hitherto offered of these well-attested revolutions have not had the merit of harmonizing with known natural laws, but have merely sought to account for one wondrous irregularity by another. At length, however, the mystery seems to be cleared up, and the revolutions in question have been traced to natural causes, in a way which, if not wholly unexceptionable, is at least perfectly rational and well founded.

The earth revolves in an orbit which has an ellipticity of about a sixtieth—that is to say, the distance of the sun in one focus of the ellipse from the middle point of the axis is equal to a sixtieth part of the semi-axis, or the earth's mean distance from the sun. Consequently the distance of the earth from the sun when furthest from it, or in aphelion, is to its distance in perihelion, or the nearest point, as 61 to 59, the greatest distance exceeding the least by a thirtieth of the mean distance. The heat received from the sun varies in the inverse duplicate ratio of the distance of the luminary. In the present situation of the earth, therefore, the heat in perihelion will be to that in aphelion as 61^2 (3721) to 59^2 (3481), or will exceed it by about a fifteenth of the mean heat. This augmentation of solar heat by the addition of a certain proportional part of it requires a few words of explanation. If the temperature of general space be assumed to be −234° Fahr. (see p. 105), then the heat felt by us above that temperature must be all due to the sun; and any latitude on the earth's surface, say 52°, which has in aphelion a mean summer temperature of 64°, or 298° above the temperature of space, will in perihelion have its summer temperature increased by a fifteenth of the last sum, or very nearly 20°, and thus raised to 84° Fahr.

At present the summer of the northern hemisphere takes place when the earth, being nearly at its greatest distance from the sun, is about to pass through the aphelion on the 2nd of July, only 11 days after the summer solstice or longest day. The heat of the summer is thereby moderated; but its duration is lengthened, as the motion of the luminary is slower in the more distant part of its course. In the northern hemisphere the length of summer exceeds that of winter by 7·8 days. Thus the quantity of heat annually shed on both hemispheres remains constantly the same, every variation of temperature being exactly compensated by an opposite variation in the time allowed for its continuance. But though the annual quantity of heat be constant in both hemispheres, its distribution is effectively very unequal. In the hemisphere whose summer is in aphelion and winter in perihelion, heat and cold are both moderated; where summer occurs in perihelion and winter in aphelion, both are felt in excess. In Australia the addition of a fifteenth to the mean amount of solar heat is at times very sensibly felt. In February 1858, and in lat. 37° 58′, not far from Melbourne, the heat of the sun under a clear sky rose to 146°; and the inhabitants of that country still remember a "Black Thursday," of previous date, when men and cattle were compelled by the scorching rays of the sun to seek refuge in the water. On the other hand, the protracted winter adds much to the severe cold of North America.

But the inconvenience arising from the unequal distribution of solar heat throughout the year may be greatly augmented by an increase in the ellipticity of the earth's orbit, which in a long course of years undergoes much change. Moreover the earth's annual course is constantly shifting its position by beginning and ending at different points of the orbit. The solstitial line passing through the sun joins the solstices or points in which the sun appears to stand at midsummer and midwinter respectively. At right angles to this line, and likewise passing through the sun, is the line which joins the equinoxes. Now these lines, though they terminate in the orbit, have no relation to or dependence on its major axis or the line that joins the perihelion and aphelion. At present the aphelion, as already stated, is but a few degrees from the summer solstice, and the perihelion near the winter solstice. But in consequence of the precession of the equinoxes the solstitial line constantly moves backwards, retreating slowly from the axis of the orbit at the general annual rate of 50·1 seconds. At this rate it would go round the orbit in 25,868 years; but the axis at the same time moves still more slowly in the opposite direction, thus accelerating the rate of their separation. Let A P (fig. 122) represent the major axis of the orbit, joining the aphelion and perihelion, and S S′ the solstitial points, near the preceding, as they actually are at present. The winter solstice (S) moves away from A so slowly as to advance barely a degree in 58 years. It would thus require 25,868 years to complete its course to A. But in the mean time the latter point moves away from S still more slowly, and meets it at A′, so that the time required for the revolution of the solstice S from aphelion to aphelion is thus reduced to 20,984 years. The equinoctial line E E making always right angles with S S′, moves with the latter, its motion on the equator being named the precession of the equinoxes.

Fig. 122.



It is obvious that in the course of the revolution thus described the equinoxes must at some time come to coincide with the extremities of the major axis, or with the aphelion and perihelion. If this happens in a period of great eccentricity, its result will be an increase of the annual heat; for the orbit, when elongated, being also narrowed, the sun's distance will be reduced for much more than half of the year. The extreme temperatures of summer and winter also will then be shared alike by both hemispheres.

Together with this change of the earth's position in its orbit (the directions of its axis of revolution remaining constant) must be taken into consideration also the inevitable change in the orbit itself. The limits within which the eccentricity of the orbit may fluctuate have been found by M. Leverrier to be ·0031 and ·7775, or from a 300th to nearly a 13th. That astronomer has investigated the whole cycle of orbital changes, and framed formulæ for their calculation. With these formulæ Mr. James Croll has calculated the eccentricity at intervals of 50,000 years for three millions of years anterior to 1800, and for a million of years in advance.

The following short extract from the Table thus formed will suffice for our present purpose :—

		Eccentricity.
Years before 1800	2,650,000	·0053
"	2,600,000	·0660
"	2,550,000	·0167
"	2,500,000	·0721
"	900,000	·0102
"	850,000	·0747
"	750,000	·0576
"	280,000	·0569
"	1,800	·0168
After 1800	800,000	·0639
"	900,000	·0659
"	200,000	·0569

At the earliest of these dates it will be seen that the orbit hardly differed from a circle, its eccentricity being little more than a 200th part of its mean diameter ; but 50,000 years afterwards it increased to a 15th. Again, in another 50,000 years it fell to about its present magnitude (a 60th), and then after a like interval rose to a 14th. 900,000 years ago it fell low ; but in 850,000 it had increased to nearly its extreme limit. After an interval of 100,000 years the eccentricity attained the magnitude of ·0576 (about an 18th), and again, 200,000 years before 1800, it rose to ·0569. Looking to the future, we find that the eccentricity will first become considerable in 800,000 years ; it will then be ·0639, and in 900,000 ·0659, or a 14th part of the mean distance.

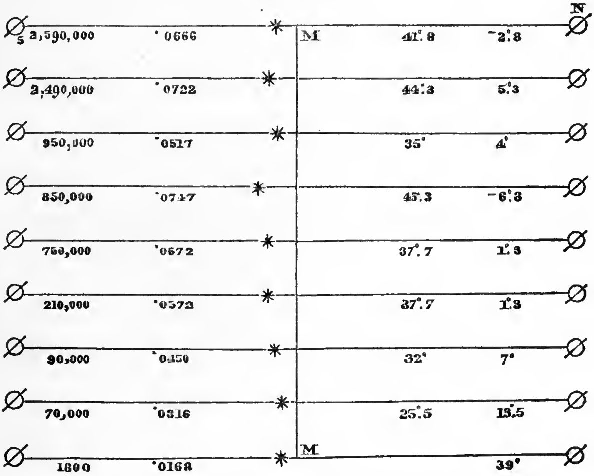
It is evident that as the eccentricity of the orbit increases, so do also the extremes of climate in the hemisphere of the earth which has its summer in perihelion and its winter in aphelion. Its summer is abridged but excessively hot, its winter prolonged and very cold. The effects of heat do not accumulate from year to year, while those of intense cold are sure to augment with time. The hemisphere whose summer takes place in aphelion and winter in perihelion experiences an equalization of those two seasons. Now the increased eccentricities of the orbit which occurred at the second, fourth, and sixth dates in the preceding Table were capable of bringing about the extreme revolutions of climate, the traces of which at present astonish the geologist. About 850,000 years anterior to 1800 the length of winter exceeded that of summer by 34·7 days ; the decrease of winter temperature was 45°·3 Fahr.—the mean winter temperature of Great Britain, now 39°, being then only −6°·8, about equal to that of Novaya Zemlya at the present day. The Glacial period, therefore, might be assigned to any of those dates. But Mr. James Croll, whose statements and conclusions are here summarily recounted, does not deem it expedient to carry back the Glacial period, of which the remaining traces show it to be geologically recent, to a distance of nearly a million of years. As the physical cause of the anomalous cold and glaciation is alone the subject of our inquiry, and not its date, we shall adopt Mr. Croll's decision, though zealous geologists will probably dissent from it.

It appears that for 50,000 years, from 230,000 to 180,000, previous to 1800 the eccentricity of the orbit was never less than ·0476. At the date of 210,000 it rose to ·0575. The depression of midwinter temperature was then 37°·7; the temperature of winter in the British Isles sank to 1°·7, or above 30° below the freezing-point. All the humidity precipitated from the atmosphere in such a temperature fell of course as snow. All this snow had to be melted in the following brief summer, before the temperature could rise above the freezing-point. Thus the summer, already shortened by the figure of the orbit, was virtually still further abridged, and was followed by a more copious fall of snow, which cooled still more the following summer. In this way the snow, by its permanence, gradually encroached on and dispossessed the summer, and then began to accumulate from year to year.

Now, according to Mr. Croll, this snow fell heavily and remained throughout the year unmelted down to lat. 55°. Its depth, he thinks, was at the pole not less than 6 (perhaps even 24) miles; but at the same time he is willing to reduce it to two miles. This great quantity of snow, it is evident, must be considered as taken from the ocean to be annexed to one hemisphere. But thus added it increases the gravitation of that hemisphere, causes the centre of gravity of the earth to be shifted towards it; and consequently the ocean too follows in the same direction, and rises higher in the snow-laden hemisphere. Its increased depth, depending on the quantity of snow, could not, our author believes, under the assumed conditions, be at the snow-laden pole less than 485 feet; but he evidently thinks that, in fact, it rose much higher. We have seen that a period of great eccentricity may continue for 50,000 years. In little more than half that time both hemispheres of the earth experience all the extremes of heat and cold attending that condition of the orbit. In general high and low eccentricities alternate within the period just mentioned. The ocean, therefore, must be constantly though slowly changing its position on the globe, passing from the more temperate hemisphere to that of extreme climate, which, having its winter in aphelion, must be loaded with snow. To this oscillation of the ocean Mr. Croll ascribes the numerous sedimentary strata of the Tertiary formation, thus explaining by the changing level of the sea what is generally attributed to the sinking and rising of the land. He also refers the coal formations chiefly to the Glacial period; and the arguments adduced in support of his views are fully as well founded and conclusive as any that serve to uphold the current doctrines of geology. But these questions, having no connexion with physical geography, need not be here discussed. It ought to be added that Mr. Croll, while arguing that with a highly eccentric orbit the hemisphere that has its winter in aphelion may probably have an accumulation of snow 12 miles in height at its pole, maintains also that the antarctic or south pole of the earth probably has at present about its pole snow heaped to the height of two miles. But if so it must increase the attraction of gravitation of the southern hemisphere; and as that must act on the atmosphere, the barometer ought to rise as it approaches the south pole.

In order to remove all obscurity from these speculations, so novel in their completeness, they shall be here very briefly recapitulated and illustrated as to their salient points by means of diagrams, representing side by side the successive modifications of the orbit. The first column of figures gives the date from 2,590,000 years before the present century to the year 1800 A.D., or the close of the last century; the second, the eccentricity of the orbit in the decimal fraction of mean distance. The third column

Fig. 123.



shows the depression of midwinter temperature caused by the increased distance of the sun in the hemisphere whose winter is in aphelion; and, lastly, the fourth states the mean midwinter temperature of Great Britain, calculated for each condition of the orbit (fig. 123).

In the earlier periods of great eccentricity there must have been extreme cold and extensive glaciation; but the surfaces that witnessed the desolation of those ages are supposed to have been long since obliterated, buried, or washed away. Evidence of those distant visitations may perhaps still be found by palæontologists in fossils of the Miocene and Pliocene ages. But the glaciation of which the proofs still remain conspicuous in striated rocks, moraines, boulders, &c. must be assigned to a much later date, perhaps from 240,000 to 70,000 anterior to the present century.

Having thus stated the views of Mr. Croll (views founded on exact knowledge and ingenious reasoning) we have now to consider to what extent they must be accepted, or what abatements they may require on account of the zeal of prepossession with which they are advocated.

It is, in the first place, difficult to believe in the existence, under any circumstances, of snow, or rather of ice (for snow in great quantity being compressed becomes light ice at no great distance below the surface), heaped to the height of 12 or even of 2 miles. When the northern hemisphere has a long and very cold winter, it has also a very hot though shortened summer. Its humidity in winter is drawn chiefly from the southern hemisphere. There the increased length of the summer does not compensate in its evaporation for the moderation of its temperature. The moisture borne from the south is precipitated in the form of snow as soon as it meets a freezing temperature—that is, long before it reaches the pole. It is quite certain that far the greatest portion of the snow that falls to form the supposed ice-cap must be precipitated on its outer limits. This, indeed, is admitted by Mr. Croll, who, however, ingeniously argues that while the fall of snow decreases towards the pole, the area on which it descends decreases in a still greater ratio, and therefore the snow must lie thicker. But this reasoning shuts out from view the facts that the north pole is in the midst of a sea which must be all frozen before it can be covered by a continuous ice-cap, and that the sea in question communicates with the equatorial ocean; and as to the difficulty of the accumulated snow escaping by melting and making its way in the fluid state to lower latitudes, how can it be seriously urged by one who believes with Mr. Meech that at the north pole in July solar heat is more intense than at the equator? If water can cut deep valleys in the hardest rocks, why should it be unable to work a passage through ice and snow? It would not be unreasonable to conjecture that the cold current which, issuing from the south-polar sea, turns, contrary to the general law, to the right instead of the left, and strikes on the western shores of South America, owes its origin to a great river of ice-cold water, fed by glaciers about the southern pole and discharged into the ocean by an opening facing the north-east.

But, secondly, it cannot be doubted that the formation of a polar ice-cap, two miles high and extending to the 55th parallel, together with the consequent transfer of the ocean and of the earth's centre of gravity some distance to the north, would materially change the precession, and thus throw into utter confusion the calculations of Mr. Croll, who, thinking to set his speculations in M. Leverrier's framework, introduces conditions which that astronomer never dreamt of and irreconcilable with his conclusions. This does not merely affect the dates of the orbital changes, but tends, by a different combination of complex causes, to produce a totally altered series. Consequently Mr. Croll's calculations as to the time and succession of the extreme states of orbital eccentricity must be all more or less incorrect. These defects in matters of detail, however, can hardly be said to impair the general correctness of his views. To him belongs the praise, first, of fully and clearly demonstrating what others had vaguely suggested—namely, that the past revolutions of climate traceable on the earth are explicable by the changes of the earth's position in her orbit, and of the figure of that orbit, that take place after long periods of years; secondly, of suggesting the cause of recurring alterations in the level of the sea, to which may be ascribed the numerous sedimentary deposits of the Tertiary formation; and thirdly, he has had the courage to condemn Sir Charles Lyell's doctrine of uniformity, generally received by geologists, which teaches us that change and progress on the earth have from the beginning always marched at the same maturely grave and steady pace as at the present day, although he unfortunately adopts that principle when he would calculate the results of denudation.

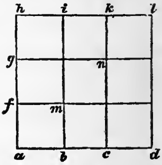
Here it may be remarked that some disposition to exaggerate the possible inclemency of a winter in aphelion is natural and pardonable in one who is intent on explaining what is ordinarily described with exaggeration. The glacial age is always spoken of as a period of intense cold. It was, in truth, a period of very abundant snow; and snow may fall from an atmosphere saturated with humidity at a temperature low indeed, but far short of intensity. There is cold enough in England every winter to cover the country with deep snow, if only the cold were accompanied by copious precipitation; but that now rarely occurs. In the glacial age, on the other hand, there never perhaps was a dry atmosphere, and what is now called "a black (*i. e.* snowless) frost" never occurred. The precipitation probably always exceeded the evaporation, and the ocean was still increasing. In fact the chief peculiarity of the glacial age, compared with the present, was its abundant moisture. A specimen of its character, no doubt somewhat mitigated, may be seen on the western coast of South America, south of the Chiloe Islands, where the vapour-laden north-west wind from the equator strikes on the southern continuation of the Andes. There the valleys are filled with glaciers, and the incessant snowfall covers the whole country from the summits of the mountains to the seashore; while a little further south, or nearer the pole, at Magalhaen's Straits (where, apart from the snow, the climate, though drier, is more severe), the humming-bird is seen flitting through vigorous vegetation. When the northern hemisphere of the earth 800,000 years hence, again with a great eccentricity of orbit, has its winters in aphelion, it will assuredly have much less snow than fell on it 850,000 years ago; but on that very account it will have to endure a far more afflicting degree of cold.

In the preceding pages it has been assumed that the most important periods in the development of the earth—periods to which geologists have given no attention (namely, those in which the atmosphere precipitated in the fluid form all the vapours originally contained in it, and in which the ocean was collected and grew till it covered three fourths of the surface of the globe)—were prolonged to a comparatively recent geological age, and that until they terminated the natural forces operating on the earth were as yet incompletely balanced. Between atmosphere, land, and ocean there still remained some variance as to limits. Torrents were then as numerous as rivulets are now. The sea changed its level frequently and irregularly; the atmosphere, giving up its impurities, underwent an important alteration by loss of weight. When all was at length adjusted, when the sun alone determined temperature, when the atmosphere supported only the vapour permitted by that temperature (precipitation being confined to the limit of evaporation), and the ocean had found a settled boundary—when, in short, the terrestrial system had attained a condition of stability,—then, and not till then, did the natural phenomena of the earth follow in a regular, equable succession, and uniformity began.

Of the changes that have taken place in the relative levels of sea and land there is abundant evidence. Of those that have affected the atmosphere the proofs are less obvious, but by no means wanting. A diminution of the weight of the atmosphere may be justly inferred from the fact that extinct species of animals, as seen in fossil remains, appear to have been collectively created on a larger scale than the corresponding species at present existing. Heavy animals were relatively more numerous, and weight rather than agility characterized the figures of all. Domesticated animals, increasing in size by care, must of course be excluded from the comparison. The connexion between the size of animals and the weight of the air is easily explained.

When bodies differing in size but with similar figures are compared, it is seen that their surfaces vary in the duplicate ratio, or as the squares, of their linear dimensions. If the line *a b* be half of the line *a c* (fig. 124), or in the ratio to it of 1 to 2, then the square of *a b* (*a b m f*) will be to the square

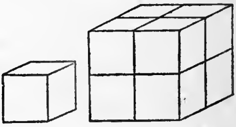
Fig. 124.



of *a c* (*a c n g*), a similar figure, in the duplicate ratio of 1 to 2 (*i.e.* as 1 to twice 2, or 4). If *a b* produced to *d* be three times the length of the former, then the square of *a d* (*a d l h*) will be equal to 3 times 3, or 9 times the square of *a b*. This holds true of all similar figures. If, therefore, two animals of different sizes but like proportions be compared, the surface of the greater will exceed that of the less in the duplicate ratio of that subsisting between their lengths.

But, again, similar figures with change of dimension increase in bulk or volume still faster than in surface. The cube of *a b* (1) is to the cube of *a c* (2) (fig. 125), not as 1 to 2 × 2 (4), but as 1 : 2 × 2 × 2 (8); and if *a d* were 3 times *a b*, its cube would be to that of the latter as 3 × 3 × 3 (27) to 1.

Fig. 125.



Thus it appears that if a body increases in dimensions its volume and weight increase still faster than its surface. The surface will be as the square, its volume as the cube of the single linear dimension. If the linear dimension be 4, the surface and volume will be respectively as 16 and 64. Now the pressure of the atmosphere (nearly 15 lbs. on the square inch), to which all bodies on the earth are subject, acts wholly on the surface; it becomes proportionally less effective, therefore, as a body grows more massive. The air offers some resistance to the motion of bodies through it, and this resistance increases in the duplicate ratio of the resisted velocity; consequently a limit is thus set to the possible velocity of any body passing through the atmosphere; and this limit is the sooner arrived at the greater is the proportion of the body's surface to its weight. Insects with numerous slender members, exposing much surface and with little weight, receive much support from the air and are never hurt by falling. They are formed to bear and to profit by a relatively great atmospheric pressure. Their chief sense is probably that of aerial vibration. The activity of the flea, compared with that of the elephant, has often been cited as worthy of admiration. The flea can leap at least a hundred times its own length ; but then it must be considered that if an elephant were to leap like a flea it would be dashed to atoms on reaching the ground. The compression exercised on animal tissue is obviously necessary to give it firmness ; but it acts most effectually on thin substances ; and, consequently, of two animals alike in all respects except in size, the smaller will be the better braced.

From what precedes it must follow that among the natural conditions which determine the structure of an animal is its adaptation to the weight and pressure of the atmosphere. As the air itself has weight, it buoys up to some extent the body it surrounds, the weight of the body being lessened by that of the air displaced by it, and more, therefore, the heavier the air. Consequently if a change takes place in the weight of the atmosphere, the animals exactly adapted to the natural conditions of their existence in the original state of the air are no longer in harmony with it in its altered state. Under a very heavy atmosphere the elephant would feel relieved of much of its weight and become a comparatively active animal. Under an atmosphere of reduced weight, he would become heavy and relaxed. Under a moderately increased weight of atmosphere a small spider might be unable to fall, and therefore could not weave its gossamer. Such changes of natural conditions would cause in individuals loss of health and altered constitution ; in the species a change of type. The elephant, framed originally under a heavy atmosphere, would necessarily, under reduced pressure, suffer loss both of size and activity, his overburdened limbs growing more clumsy. The same reasoning applies with little change to all that moves and breathes in the atmosphere, and may serve to account for the gigantic scale suited to a heavy atmosphere, and so often exhibited in the relics of past creations.

CHAPTER XXX.

The received views of Creation.—The Earth not at first liquid.—The Origin of the Ocean and of Mountains.—Denudation.—Volcanoes incidental and not permanent.—Subsidence and Rise of Land.—The Natural Hypothesis of Creation.—The gathering of the Ocean.—Fracture of the Earth's Crust—its consequences.—Change of Level attributable to the Ocean.

While physical geography treats of the natural phenomena of the earth and their various modifications over its surface, geology confines itself to the material structure of the globe ; but though these two branches of study follow distinctly different paths, it may yet be expected of them that they will agree in recognizing the same code of natural laws ; for why should it not be supposed that the system of law which now governs the world is that under which it was created ? It is worth while, therefore, to inquire whether some conclusions adopted by geologists have not a character widely different from that of the demonstrated laws of the universe.

It is now generally assumed that the solar system was formed from nebular matter in the manner described by Laplace, a great nebula, thinly spread over the whole area now occupied by that system, being reduced by gravitation and revolution to the sun or central body and the planets revolving round it in elliptical orbits. This conclusion was the necessary consequence of viewing comprehensively the motions of all the bodies in the system and of retracing those motions to their origin. The most remote planet, Neptune, was first formed ; then Uranus, Saturn, Jupiter, &c. ; till at last the condensation reached the centre, where the predominant attraction remained fixed. Thus time elapsed in the successive formation of the planets ; and as the production of the whole system was not instantaneous, so neither is it necessary to suppose that any single member of it was formed instantaneously ; such production would be pronounced by a chemist impossible.

It is stated in geological treatises that the earth, when it first took its place as a planet, was a liquid globe, having been fused by the heat attending its reduction from the gaseous state; but Bischof has pointed out that the heat generated by its condensation (supposed to be instantaneous) would be sufficient to volatilize and disperse all its materials. No reason can be assigned for attributing to it the heat of fusion. In order that it should take the spheroidal figure, it was not necessary that it should be fluid. There remains no trace on the earth of its original fused condition; but a wrong hypothesis tends to exclude the truth. Since aerolites are continually falling on the earth, why might they not have fallen in the first instance? Why may not the earth, at least the exterior part of it, have been formed of mineral particles solidified before they met to form a globe? If we inquire what is sand, we are told that it is quartz or some siliceous rock ground to atoms; if we ask what is clay, we learn that it is felspath or some aluminous rock triturated and reduced by friction. We thence conclude that hard rocks preceded sand and clay. But, again, if we seek to learn the origin of hard rocks, we are informed that they are composed of particles of silex or of clay cemented together and hardened by compression. Here, then, the sand and clay precede the rocks. On such infirm ground there can be no base for reasoning. Let us assume, then, as the simplest and most natural hypothesis, that the earth was in the first instance strewed over with mineral particles of all kinds and sizes, not compact nor compressed, but tolerably even, the heavier kinds below, the lighter on the surface.

It is natural to suppose that the earth, formed by revolution and the attraction of gravitation, was in the beginning a perfect spheroid, as symmetrical as if it had been turned in a lathe. Moreover, owing to the excessive heat attending its solidification, there could not have been any permanent fluid on its surface. This must be admitted by all who believe that it once existed in a state of fusion. If, then, it began as a spheroid perfectly dry and symmetrical, how are we to account for its present inequalities, its high mountains, and its deep ocean? As to the origin of the ocean, geology is strictly silent; as to mountains its information is ambiguous or equivocal and altogether unsatisfactory. Where there are no signs of earthquake or volcanic actions, some hold that mountains grew up or were gradually raised; others regard them as relics of the original plain, the rest being swept away by denudation. Geology starts from a period long subsequent to the creation, and tells us that in the beginning there was land and sea as at present, though otherwise distributed; that the conformation of the earth's surface has been continually undergoing and still undergoes important change, the land being worn down by denudation and swept into the deep, while volcanoes and earthquakes raise new land from the ocean. But it is asserted also that, independently of denudation and volcanic eruption, the work of change is carried on by subsidence of the land and by its emergence again—an unaccountable, irregular, lawless agency, which, however, serves to explain the successive formation of the stratified rocks. This slow and imperceptible sinking and rising of the ground (quite distinct from the violent effects of earthquake and denudation, though frequently confounded with them) forms the most indispensable and at the same time the most incomprehensible article of the geological creed.

The effects of denudation, we are told, are calculable. The land is worn away, and has been wearing from the beginning, at the uniform rate of at least a foot in 6000 years. This is deduced from the growth of the deltas of the Mississippi, Ganges, and other great rivers. Then, again, the waves of the sea wear away the sea-coasts. In some places large tracts of sea-shore are annually carried off; but all these instances fail to prove a uniform and indefinite impairment of the land. Rivers wear down their beds; the more deeply these are cut the less is the waste caused by inundation. The violence of a flood depends on its velocity and the slope of its channel; but it is continually carrying down materials, filling up the lower part of its channel, and thus losing its impetuosity. There are many examples of rivers which have barred up their mouths, and then terminating in marshes are wasted by evaporation. If they carry their sediment to the sea, they form banks or deltas and make additions to the land. Thus the Nile has not washed away Egypt, but has raised and extended it. When the sea ravages a shore, it never carries the detritus to a distance, but spreads it out in front of its former position, and forms a bank or shoal, which ultimately breaks its force and sets a limit to its invasion. Thus the chalk cliffs of Kent are everywhere protected by the sea-formed low ramparts thrown up before them. The beach at Deal has been formed by the sea, and is daily repaired by it. It is obvious that in all these cases there can be no such thing as uniform progress. Denudation of every kind tends to a certain point where the resistance becomes equal to the attacking force. Its power is always decreasing; and however long it may continue, the sum of its effects is strictly limited.

We cannot believe that wind and weather wear away the hills and plains covered with vegetation; nor do we see any traces of the assigned denudation on the sculptured marbles which have been exposed to rain and sunshine for at least 30 centuries. They appear to have suffered chiefly from fracture and attrition; none of them have uniformly lost six inches from their surface, and not a few retain much of the original polished surface, and so far have not been worn at all. Surely the snow-clad summits of Gaurisankar and of Chimborazo are preserved intact from denudation, and the grassy slopes of the Abessinian mountains, 14,000 feet high, are not liable to be washed or blown away; but then that awful, imperceptible subsidence of the ground, which is absolutely required for geological theory, may be expected in due time to sink them in the ocean. Well, if the subsidence in question does not proceed a great deal faster than it has done during the last 3000 years, the catastrophe attending it is so distant that it does not deserve a moment's consideration.

It is true that Jorullo, in Mexico, rose in a short time to the height of 1550 feet, and did not fall back again as the sudden products of volcanic eruption usually do. An extensive tract along the coast of Chile was raised 5 feet by an earthquake in 1822, and again subsided about 2 feet. Southern Italy furnishes abundant proofs of the changes wrought by earthquakes and volcanoes. Many ancient roads about Naples lead down to the sea, where they abruptly terminate, the places to which they led being now beneath the waves. The Temple of Serapis, near Pozzuoli, built high above the sea, was plunged in it to a depth of 18 feet, and, with columns corroded by marine boring-worms, is now again raised above the waves.

When in the year 79 A.D. Herculaneum and Pompeii were overwhelmed with lava and volcanic ashes from Vesuvius, there remained no tradition of that mountain's previous eruptions; yet beneath the soil on which Herculaneum was built is a thick layer of ancient lava, and below that again, 146 feet from the present surface, a soil with marks of industry. But these irregular fortuitous commotions, which generally end in elevating the ground, have evidently no connexion with the alternating movements up and down, by means of which geologists seek to account for the numerous series of sedimentary deposits that form the later and stratified rocks. But as the highest geological authorities inform us that volcanoes are in course of extinction, and that the comparatively few which remain in activity are incomparably weaker than those of past ages, it is needless to discuss their share in the abiding physical system of the earth.

But we have still an array of facts or statements to consider, apparently more difficult to deal with. The eastern coast of Sweden, in the Gulf of Bothnia, is rising, we are told, at the rate of 3 feet in a century. But since this movement is confined within certain limits (for Scania to the south does not rise, nor Torneo, we believe, to the north), the centre ought to be fixed of the arch thus formed by the rocky crust of the earth, supposed to be 20 or 30 miles thick. The northern shores of Siberia also are said to be rising, the western shores of Greenland to be sinking. From all parts of the earth accounts are received of some small vertical movements of sea-coasts, all ingeniously adapted to the geological opinions in vogue. Now as to the nature of these movements, is it necessary or natural, or consonant with what we know of physical laws, to impute them at once to a very slow and perpetual motion and change of figure in the crust of the globe? If rocks be still undergoing metamorphosis, may they not swell with the change, and thus rise to a small extent? May not the ground still imbibe oxygen and dilate? If shores be formed of various strata, may not one or more of these be washed out, and thus cause a subsidence? Is it certain that gravitation is locally constant, or that the disturbed level of the sea, owing to persistent winds, is promptly adjusted? If a man sees a bean grow 4 inches in as many days, he is not thereby justified in concluding that it will in ten years reach the height of 300 feet. In like manner there is no ground for concluding that the rising shores of Sweden will attain the height of 300 feet in 10,000 years. The doctrine of the rise and the subsidence of land is founded not on actually observed facts, but on arbitrary inferences from supposed, nay even imperceptible, facts; for the geologist dwells much on that slowness of movement that escapes the perception of all but the initiated.

The ability and industry by which geology has been raised within little more than half a century to its present rank cannot be overrated; yet in order to give it the appearance of a science, with all things explained, Sir Charles Lyell found it necessary to adopt some provisional hypothesis; but though thus rendered complete according to its first design, geology may possibly be still improved by change of first principles. The doctrine of continual, slow, and imperceptible change discrediting experience conceals much fallacy. Land, forsooth, incessantly sinks into the sea or rises from it; yet the ocean shows no symptom of such disturbance, and mankind have no suspicion of the fact. But what signifies the experience of 3000 years or the time of history, which is but an incalculably minute fraction of geological time?

The doctrine of uniformity has an appearance of extreme sobriety and lulls suspicion; but it has also the effect of lengthening immeasurably the traceable periods of the earth's development, and it removes beyond the reach of vision the miracle of creation (for creation was a miracle), and confines the view within the bounds chosen by the geologist. It would, however, be a tedious labour to examine in detail the whole fabric of geology, reared as it has been to a great height with admirable perseverance and ingenuity. It will be a more brief, and perhaps a more agreeable, course to sketch anew the early history of our globe, and to direct attention to some stages of its development which have hitherto escaped attention, though obviously of the greatest importance.

The globe when first formed may be naturally supposed, as already stated, to have been a spheroid of perfectly uniform surface, solid and dry, its intense heat not allowing any fluid to rest upon it; consequently all the water now on the earth, probably in volume above 500 millions of square miles, then floated in the atmosphere. But the day came, as the globe cooled, when the water, at a temperature just below the boiling-point, began to fall. It immediately seized on the silex, and the solution sinking in the ground cemented the siliceous rocks. As lime is more soluble in cold water, the consolidation of the calcareous rocks took place later. Doubtless the fragmentary mineral surface, not as yet compressed, sank in many places under the water that poured on it; where perfectly uniform in quality, it formed circular pools; into these flowed streams from the surrounding plain; but as the weight of accumulated water increased, the ground beneath it gave way, the pool deepened and became a great lake. It is easy to understand how, by the continuance of this process, the water constantly collecting, the ground sinking beneath it, lakes became seas and seas grew to be great oceans. Let it be considered that the present ocean would suffice to cover the solid globe, were its figure regular, to a depth of nearly three miles, that the rainfall at present just equals the evaporation, but that while the ocean was falling to the ground it increased only by the excess of rain over evaporation, which under all the circumstances must have been immeasurably greater than at present. It is evident, then, that uniformity is here totally out of the question, and that the torrents of rain and the floods rushing in all directions over the earth during the growth of the ocean had a magnitude and force never since approached. As the sea collected, its bed from time to time sank deeper; the level of the sea then fell, but was again raised by fresh influx; and thus the ocean in the course of its formation, which may have lasted for thousands of years, has stood at many levels. It may have been much higher than it is at present.

The most remarkable and distinguishable period in the early history of the globe was that which embraced the gathering of the waters. That was manifestly the age of denudation. It was then that valleys, miles deep, were dug out by the rushing floods, and that drift and detritus of all kinds were spread far and wide. Nor was this all. The sea-bottom, it is now ascertained, sank in some places above five miles. Its cavities are now for the most part concealed by sedimentary deposits ; but it can hardly be doubted that this sinking was in many or even most cases attended with fracture of the earth's crust, so that the flood rushed in to encounter the intense heat of the interior. The overpowering force of steam thus called forth threw up the fractured rocks to a great height ; earthquakes changed the face of the earth, and volcanoes arose pouring out melted lavas, and proving that communication still exists between the fires of the interior and the surface of the globe.

When the main lines of earthquakes and volcanoes are comprehensively surveyed, it seems impossible to doubt their connexion with the sea. They mark out the shores of the Pacific Ocean with little interruption throughout. The Cordilleras of the Andes and the Rocky Mountains of North America appear to have been raised by volcanic force. The wide strip of land between those mountains and the sea was apparently upheaved with them, or formed from them by denudation. The Aleutian and Kurile Islands, with the peninsula of Kamchatka, are all volcanic. Proceeding along the Asiatic coast we find volcanoes in Japan, Java, and Sumatra. Further on they appear in the Red Sea and, on the eastern side of Africa, in the Comoro Islands and Madagascar. Going westward we find them in the West-Indian Islands, as well as on the shores of the Caribbean Sea and of the Gulf of Mexico. In Iceland, the Mediterranean Sea, and the eastern side of the Black Sea (in Caucasus) they assume formidable proportions. Volcanic cones are profusely scattered over the ocean. Volcanoes at a great distance from the ocean are comparatively very few and inactive. They may have been reached by cavernous passages from the depths of ocean, or inland seas now dried up (as in Turkestan) may have existed near them. Here it may be remarked that volcanic activity admits of many explanations ; there is, however, but one that accords with their almost constant contiguity to the sea.

Perhaps it will be said that the account given in the preceding pages of the formation of the ocean and its effects is but a work of fancy, having no solid foundation; yet it is quite certain that the ocean, though not created in contact with the earth, now lies upon it, depressing it deeply, and that it has, apparently by indirect means, effected great changes on the earth's surface. Any natural, unadorned statement of these facts is more in accordance with truth than their suppression. The most remarkable and eventful crisis in the history of our globe is passed over in silence by the geologist, who begins his history of the earth's formation with uniformity and the established routine of nature; that is to say, he supposes equilibrium to be established, the conflict of natural forces being at an end, and the earth's system complete, and yet affects to start from the beginning.

The structure of the earth, so far as it is revealed on or near the surface, is sought to be explained by two agencies: 1st, denudation or wear and waste, the scooping out of valleys and spreading of plains at a uniform rate and without limit of time. But in this postulate of unlimited time lurks much sophistry, for it excludes or dispenses with actual experience. If we endeavour to retrace this denudation, calculated with so much confidence, the state of things at the beginning seems quite incomprehensible. The age of the earth, reckoned from the date of the metamorphic rocks, is, according to the highest authorities, perhaps 300 millions of years. Now denudation proceeding uniformly during that time at the rate of a foot in 6000 years, must have lowered the earth by 50,000 feet, or more than nine miles. Gaurisankar must have been originally 14½ miles high. If all that waste has sunk in the ocean, how unlike to a regular symmetrical spheroid must the earth have been when new and unworn. Some would now limit its age to 100 millions of years, reducing our embarrassment to one third; but that is still too much.

Again, successive strata of different kinds are accounted for by the subsidence of land; it sinks beneath the sea to receive its load of sediment, as the camel drops on its knees, and then rises; but, more patient and accommodating than the camel, it takes as many loads as the geologist is pleased to impose on it. This assumption of the unlimited sinking and rising of land is plausible and convenient, but it is inexplicable and unproved.

But is it not evident that the changes of level now generally ascribed to the land may as well be attributed to the sea? The ingenuity and perseverance which have done so much with an assumption which has no merit but that of satisfying the exigency of a theory, could not fail to succeed with a substitute which is real and rational. In referring changes of level to the sea they would have this advantage, that their investigations might enable them to test the justness of their conclusions. The shiftings of the ocean described in the preceding chapter would cause changes of level increasing with latitude. Let, then, the sea-marks on rocks, raised beaches, strata of marine character, &c. be noted from Portugal to North Cape, from Brazil to Cape Hoorn, and on the coasts of New Zealand; and if they be found to rise towards the poles, then they must evidently record the changed level of the ocean. Of course the testimony of coral islands must not be neglected. But cases may occur of coral islands above the level of the sea, and near the equator, which must be considered as remaining from the age when the ocean had not yet sunk to its present bed.

THE END.

Printed by Taylor and Francis, Red Lion Court, Fleet Street.