THE REALM OF NATURE

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AN OUTLINE OF PHYSIOGRAPHY

BY

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PREFACE TO SECOND EDITION

It is the aim of this volume to illustrate the principles of science by applying them to the world we live in, and to explain the methods by which our knowledge of Nature has been acquired and is being daily enlarged. An attempt is made to define the place of physical science in the sphere of human knowledge, and to show the interrelations of the various special sciences. In this, philosophical speculation has been avoided as much as possible, and an effort has been made to present a consistent system of the Universe developed from a few simple general principles, the truth of which must be assumed. It is possible that other systems might be developed with equal truth from different premises; but that which is given here appears to the author to be liable to as little exception now as when it was first adopted twenty-three years ago.

Attention was then called to the breaking down of the old hard and fast divisions between the various special sciences; the impassable barriers were practically reduced to two—that separating matter and energy and that separating the not-living and the living. The most recent advances published during the revision of this work—too late to be fully incorporated—suggest that matter and energy may be mutually convertible, while the barrier between the not-living and the living has been so attenuated as to afford a glimpse of the possibility of continuous development.

The greater part of the book is occupied by an outline of the more important facts regarding the structure of the Universe, the form, material, and processes of the Earth, and the relations which they bear to Life in its varied phases.

The Fahrenheit scale of temperature and the British system of weights and measures are used throughout, not that they are necessarily better than other systems, but because they are still the most familiar to the class of readers expected. The illustrations in the text are merely diagrams.

The publisher, Mr. John Murray, the third of the name, made valuable suggestions for the first edition, and the title of the book, *The Realm of Nature*, is due to him. Much help was also generously given by friends and teachers, including Sir John Murray, of the *Challenger* expedition, Professor James Geikie, Professor J. Arthur Thomson, Mr. H. M. Cadell, of Grange, and in a special degree the late Lord Kelvin, Professor P. G. Tait, Professor R. Copeland, and Dr. A. Buchan.

The revision of the work for this edition has been thorough; scarcely a page has passed without alteration, while large sections have been rewritten and numerous paragraphs have been added. Many of the illustrations have been redrawn and several new figures have been introduced.

In making this revision the author has received much kindness from many friends, and he must acknowledge in particular the help given by Mr. R. B. Lattimer and Mr. Alan G. Ogilvie.

H. R. M.

July, 1913.

PREFACE TO THIRD EDITION

A general revision has been carried out. A new series of maps has been specially compiled by the author and drawn on Mollweide's equal-area projection by the late Mr. Donald S. Salter. This projection is peculiarly adapted for the representation of the distribution of phenomena on the Earth's surface, as the areas shown are equivalent in all parts of the map, although outlines are necessarily somewhat distorted towards the outer edges.

H. R. M.

15th *December*, 1923.

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CHAPTER I

THE STUDY OF NATURE

Physiography means literally the description of Nature. In order to describe anything we must know something about it, and in order to know something about anything we must study it. Knowledge obtained by the best method of study is science, and it differs from knowledge otherwise obtained in being so clear and definite that every step leading to the final result may be recalled and tested, if any doubt should arise as to its trustworthiness. Hence description based on science is clear and full, and this is the kind of description required in Physiography.

Nature is taken as including all that exists outside our own thoughts; not only all things but also all the changes they undergo. The scope of Physiography is thus immense but not unlimited. It includes everything of which we can gain knowledge in the Earth and beyond it, and every change now happening or of which a record has been left, together with the causes of all these changes. It is, however, customary to exclude the First Cause of all from consideration in connection with the account of facts and immediate causes. Theology—the study of the Creator—is in itself an immense field of science, and although it is concerned with the origin of Nature, it may be readily separated from the study of natural facts and phenomena. A sufficient reason for separating Theology from Physiography is that authorities are greatly divided as to the right means of studying the former science, while every one is agreed as to the right method of studying Nature.

Science is organised and accurate knowledge, and consequently it has no limits. Science is necessary in order to understand Nature, and while it deals with everything, its first duty is to classify by taking account of observed resemblances and differences in things. A simple and comprehensive classification capable of being extended as the number of facts increases is a necessary framework for all effective knowledge.

Comparison and Description.—Suppose that we were comparing the tastes of different kinds of fruit in a garden. It is not enough to pluck bunches of red currants, black currants, gooseberries, and raspberries off the bushes and eat them. Each bunch must be classified into berries and leaves or stems; the former are to be tasted, the latter to be thrown away and thought no more of. Without this precaution the taste of gooseberries might be compared with that of black currant leaves, and different tasters would give irreconcilable reports. When we compare the various things around us, a preliminary classification is quite as much required to ensure that we compare things that are comparable. If we were to take into account *mountains*, *pain*, *rivers*, *happiness*, *air*, *beauty*, and *motion*, the description would be very confused and puzzling. When several people who have had the same opportunity of seeing, describe an event, the descriptions are almost sure to differ among themselves. This is because a different impression is produced on each mind, and the various subjective sensations of interest, or fear, or pleasure, or surprise, are confused to a greater or less degree with the objective facts. A scientific description should be as free as possible from all subjective colouring; a mountain must not be described vaguely as impressive in its grandeur or beautiful in its colouring, but its height, the angle of its slopes, the nature of its rocks and vegetation must be specified. Nature presents us with so many phenomena to observe, and these are to all rightly constituted minds so full of wonder, beauty, and charm that we are apt to be dazzled and distracted, and even if our interest is roused it is too often satisfied by the first superficial impressions. It is only by getting beneath these and looking at bare facts and abstract principles that we can truly understand our natural surroundings and so fully appreciate "all the wonder and wealth" of the Universe in its deepest meaning. In other words we must first comprehend the things about us before we can take pleasure in them to the highest degree.

Real Things.—The first classification of things is into (*a*) Things that exist only in our own minds; (*b*) Things that exist outside of us and independent of us. Emotions, feelings, tastes, and beliefs belong to the former class and are termed subjective things. Facts and phenomena which exist whether we know of them and think of them or not, are termed objective, and these we may call in a special sense *real* things. The real things of Nature are the objects of physical science, and they alone fall to be considered here. The one test of reality in Nature is essential permanence notwithstanding changes of form. Only those things are real, as we use the word, which can neither be created nor put out of existence by human power. Subjective things, such as pain, happiness, beauty, may be readily produced and destroyed, hence however vivid the impression of them may be they are not real, in our sense of the word, and form no part of Physiography.

Definition of Physiography.—Physiography is a description of the substance, form, arrangement, and changes of all the real things of Nature in their relation to each other, giving prominence to comprehensive principles rather than to isolated facts. This definition of the *term* Physiography is simply a definite statement of the meaning of the *word* Physiography, as given in the opening paragraph.

Use of the Senses.—Our senses may be viewed as the windows through which alone knowledge enters the mind, and through which alone we are able to study the things outside us. Instruments and apparatus, no matter how elaborate and complicated they may be, are of value only in making the senses more efficient or in applying them more advantageously to the object of study. All the senses—sight, hearing, touch, and the less used smell and taste—are limited in their scope, and liable to get out of order through disease or neglect. But even when in full health and within their own range they are not quite trustworthy. If an object present different appearances when looked at through different windows, we are justified in believing this to be due to imperfections in some or all of the windows. A few simple experiments show us that this is the case with the windows of knowledge. Optical illusions prove the imperfection of the sense of sight. A coin spinning quickly looks like a hazy sphere, but we know it to be a flat disc. Strobic circles which seem to whirl rapidly when the card on which they are printed is moved slightly, and designs appearing in their complementary colours on looking at a blank wall have been made familiar by their use as advertisements. Mountains seen in front look steeper than they are; in a haze on a snowy plain a mouse close at hand has been mistaken for a distant musk-ox, and familiar objects are often passed unrecognised in unusual places. A simple experiment shows that touch is as fallacious as sight. When a pea or small ball is rolled on a table by the middle finger crossed over the forefinger of the same hand, so that both fingers touch the object, the impression produced is that there are two peas, not one. Similarly if one hand has been held in hot water and the other in cold water, and then both are plunged into a mixture of hot and cold, the mixture will be pronounced cold by the hand previously heated and hot by the chilled hand. The deceitfulness of the senses may impose upon the most acute and practised mind if taken unawares. When Sir Humphry Davy discovered potassium he showed a piece of it to Dr. Wollaston, one of the most accurate observers who ever lived. Wollaston saw the silvery lustre of the new metal, weighed it in his hand and said, "How ponderous it is!" Davy in reply threw the metal into a basin of water, where it floated lightly on the surface. Wollaston's illusion is the more striking because at that time he was the only man who was in the habit of handling platinum, a metal which, bulk for bulk, is twenty-five times heavier than potassium.

Use of Reason.—In spite of such cases of deception, we trust our senses and are rarely deceived by them. Reason, man's supreme gift, examines, weighs, extends, and judges the evidence of the senses. It requires a course of reasoning to let us know that a tall man seen on a straight road is not a dwarf close at hand, or that the Moon rising behind a wood is not a yellow disc hung in the trees. Long practice has made the operation of reason so swift and smooth that we are seldom conscious of an interval between seeing and understanding. Reason makes the senses satisfactory means for acquiring knowledge, although reason alone can give no information about natural things. Just as the senses may be greatly aided by instruments and apparatus, so reason may be greatly aided by mathematics. And as accurate measurements, on which the value of all scientific observations depend, can only be made by means of suitable apparatus, sometimes of a very elaborate nature, so accurate reasoning, which is essential in all scientific discussions, can only be fully carried out by mathematical processes which are sometimes difficult and complicated.

Common Sense is the name which practical people give to the faculty of getting directly at the truth of a question, and keeping free from prejudices and fallacies. Common sense is simply reasoning on the evidence of the senses, without keeping account of the process. This common-sense method merely requires to be made precise and accurate in order to become the Scientific Method of gaining knowledge. The two guardians of thought in science are *Accuracy* and *Definiteness*. The scientific man deals with phenomena as the banker does with money, counting and recording everything with scrupulous exactness. The student should remember that for the practical purposes of life the knowledge of what are called scientific facts is unimportant compared with the power of using the scientific method. It is really more scientific to repeat a quotation from a political speech correctly, or to pass on a story undistorted, than it is to know of the rings of Saturn or the striation of diatoms.

Accuracy in observation usually takes the form of correct measurement of mass, space, or time, by means of suitable instruments. Accuracy is always to be striven for, although absolute accuracy can never be attained. This fact is only fully realised by scientific workers. The banker can be accurate because he only counts or weighs masses of metal which he assumes to be exactly equal. The Master of the Mint knows that two coins are never exactly equal in weight, although he strives by improving machinery and processes to make the differences as small as possible. When the utmost care is taken the finest balances which have been constructed can weigh a small object with an uncertainty less than one forty millionth part of the total weight. In other words, the weight is not absolutely accurate, but the inaccuracy is almost inconceivably small. In weighing out tea or sugar a grocer is content if the inaccuracy is not more than about $\frac{1}{500}$ of the mass. To take another example of varying degrees of accuracy, no person is so stupid as not to feel sure that the height of a man he sees is between 3 ft. and 9 ft.; some are able by the eye to estimate the height as between 5 ft. 6 in. and 5 ft. 8 in.; measurement may show it to be between 5 ft. 6¾ in. and 5 ft. 7 in., but to go closer than that requires many precautions. Training in observation and the use of delicate instruments thus narrow the limits of approximation. Similarly with regard to space and time, there are instruments with which one-millionth of an inch, or of a second, can be measured, but even this approximation, although far closer than is ever practically necessary, is not accuracy. In the statement of measurements, however, there is rarely any meaning in more than six significant figures, and only the most careful observations can be trusted so far. The height of Mount Everest is given as 29,002 ft.; but here the fifth figure is meaningless, the height of that mountain not having been measured so accurately that two feet more or less could be detected. Similarly the radius of the Earth is sometimes given as 3963·295833 miles, whereas no observation can get nearer the truth than 3963·30 miles.

Definiteness in thought and description does not require perfect accuracy in observation. We must always be definite in order to be clear. If he wishes to be definite in thought the student must never rest content with the dubious "I think" or the vague "about," but endeavour after the clear "I know" and the precise "with a probable error of." Vagueness and indecision are utterly foreign to the scientific method. It often happens that there is no definite knowledge concerning some fact; then all that the scientific method of description permits is to say, "There is no information," and to wait until the scientific method of observation has found out something. The difficulty is not overcome by guessing, or by calling the unknown unknowable. There is a place for speculation and imagination in the scientific method, but it is a place apart, which must be shut off, for if speculations are not kept in strict quarantine they are sure to infect our conceptions of facts with their own fatal uncertainty.

Scientific Terms.—Definite words are necessary for the expression of definite ideas, hence scientific terms have to be employed. A term has one definite meaning which does not change with time. The rush of affairs drifts words from their original meanings, as ships drag their anchors in a gale, but terms sheltered from common use hold to their moorings for ever. The word *let*, for example, has drifted in 300 years from meaning *hinder* until now it means *permit*; but the term *bisect* has remained unaltered in significance for twenty centuries. Many scientific terms are derived from the Greek and have an unfamiliar appearance; a list of all those employed in this book, together with their derivation, is given in Appendix III.

Classification of the facts and processes of Nature is necessary before we can form definite ideas concerning them; but the definiteness of classification is an artificial restriction. In Nature one thing merges into another by imperceptible degrees, and although, for example, we can readily class typical metals and non-metals, typical igneous and sedimentary rocks, typical plants and animals, there are in each of these pairs of classes some cases which cannot be referred with certainty to either side of the dividing line. Nature is discrete only within certain limits, and its classes are never so sharply defined as to isolate one from another, the unity of Nature being as marked as its diversity.

Natural Law is the order in which things have been observed to happen. The fact that there is order and not chance in the way things happen is one of the chief discoveries of science. It is the discovery on which all science depends, because knowledge could never be definite and accurate if it were not based on orderly phenomena. It is impossible that there can be any exception to a law of Nature, or any contradiction of it. Much has been written as to the impossibility of miracles because they would be breaches of the laws of Nature. If there is evidence, however, that a miracle did happen, the law of Nature it appears to contravene must be restated so as to take account of the new phenomenon. It is because the law expands to admit apparent exceptions that we say there can be no exceptions. We have, strictly speaking, no right to assume that things will continue to happen in the order in which they have happened hitherto. Nothing in time past has been more regular and uniform in its recurrence than the appearance of the Sun rising and setting. This regular order is a natural law, yet we cannot say certainly that the Sun will rise to-morrow; merely that its rising is very highly probable. The law of gravitation, the laws of heat, light, sound, and of all other observed facts, are similarly the summary of observations in the past; and although each new verification increases the probability that the laws will continue to hold good, that probability never becomes certainty.

Probability.—The probability of 83,000,000 to 1 is so great that all but very cautious people think of it as certainty. It represented the chance of a passenger arriving alive at the end of a railway journey in the United Kingdom in the year 1907. The probability that the Sun will rise to-morrow is far greater than this, although human experience does not record 83,000,000 sunrises, because no failure has ever been recorded in the past. The laws of Nature, although only expressions of very high probability as regards the future, may be assumed as certain for all the practical purposes of life.

Cause and Effect.—The relation of Cause and Effect is the fundamental law of Nature. There is no recorded instance of an effect appearing without a previous cause, or of a cause acting without producing its full effect. Every change in Nature is the effect of some previous change and the cause of some change to follow; just as the movement of each carriage near the middle of a long train is a result of the movement of the one in front and a precursor of the movement of the one behind. Facts or effects are to be seen everywhere, but causes have usually to be sought for. It is the function of science or organised knowledge to observe all effects, or phenomena, and to seek for their causes. This twofold purpose gives richness and dignity to science. The observation and classifying of facts soon become wearisome to all but the specialists actually engaged in the work. But when reasons are assigned, and classification explained, when the number of causes is reduced and the effects begin to crystallise into essential and clearly related parts of one whole, every intelligent student finds interest, and many, more fortunate, even fascination in the study. It must be remembered that cases may arise in which it is clearly recognised that two sets of phenomena are associated and dependent on each other, without it being possible to say which set is the cause and which the effect. Thus, the obvious association of environment and living organisms suggested to Paley that the environment was adjusted to suit the organism, and to Darwin that the organism was modified by the environment.

Inductive and Deductive Reasoning.—Reason may be applied to the study of facts in two different ways. *Inductive Reasoning* is the arduous process of finding the meaning of phenomena by collecting and classifying facts and thinking out their causes. *Deductive Reasoning* is the shorter operation of finding what effects must result from the operation of a known cause. It is often supposed that since we can observe facts alone the inductive method of reasoning is the only one which can be employed in studying Nature, but the number of facts even in one small department is so great that life is not long enough for the labour of collecting, classifying, and discussing them all.

The Scientific Method of discovering the causes of phenomena involves the use of both inductive and deductive reasoning linked together by *imagination*, a mental power which is as essential to the scientific discoverer as it is to the poet. After observing a considerable number of facts the investigator imagines a possible cause or explanation, and this possible explanation is termed a *hypothesis*. Then he reasons deductively from the assumed explanation, usually employing mathematics for the purpose, and so arrives at a number of additional facts which must exist if the hypothesis be true. These predicted facts may not be familiar or may not occur naturally at all. In the latter case it is necessary to seek them by making *experiments*, and so important is this aid in some cases that the expression Experimental Science is often used in the sense of physical science. If the facts predicted to exist in certain circumstances by hypothesis are not found, and if others which the hypothesis could not account for appear, the hypothesis is proved to be erroneous, or, at least, incomplete. Renewed inductive reasoning from the wider basis of ascertained facts must then furnish material for a fresh effort of imagination and a new hypothesis to be similarly tested, and, if necessary, rejected in turn. Should the facts agree with those deduced from the hypothesis there is a probability of its being true, but a great many tests must be thought of, applied, and found realised before the hypothesis can be accepted as a true and complete explanation. An explanation of facts found, tested, and proved to be true and complete in this way is called a *theory*, and when a theory is confirmed by a great number of observations it is accepted as a Law of Nature.

Proof of a Theory.—The process of testing a hypothesis requires great caution in order to prevent mistakes. A long time and the labour of many observers are often necessary to perfect a theory or demolish an incorrect hypothesis. When Newton imagined the hypothesis of universal gravitation, according to which the force that causes a stone to fall to the ground also controls the motion of the Moon round the Earth and of the Earth round the Sun, he deduced from the hypothesis that the Moon in its orbit should fall toward the Earth 16 feet in a minute. Careful observation of the Moon's motion showed that it was only bent toward the Earth 13 feet in a minute, and therefore Newton abandoned his hypothesis as untrue. Thirteen years later Picard's measurement of the size of the Earth, and consequently of the distance of the

Moon, gave him more accurate data, and on making use of these he found that the discrepancy vanished. Newton's laws are true of the working of gravitation within the solar system and are not displaced by Einstein's theory of the nature of gravitation.

Test of a Law of Nature.—A law of Nature has no exceptions; the only test by which a theory can be accepted as of this rank is the successful prediction of future effects. The theory of gravitation enables astronomers to calculate the relative position of the Sun, Moon, planets, and stars as seen from any part of the Earth's surface. This is regularly done by a government office in London, and the positions for stated times each day are published three years in advance in the *Nautical Almanac.* From the tables of that work the captains of ocean-going vessels are able to work out their exact place on the ocean by observations of the positions of the heavenly bodies. The smallest deviation from truth in the expression of the law of gravitation would throw the results into confusion and lead to almost certain shipwreck. No such confusion has ever occurred, and every successful sea-voyage is one proof more that the law of gravitation was fully understood in the past, and holds in the present. The appointments for the appearance of the Sun, Moon, and planets amongst special groups of stars at definite times made in the *Nautical Almanac* are analogous to the appointments for the arrival of trains at stations made in official railway time-tables. Observation of the fulfilment of time-table predictions, even on the best railways, soon demonstrates that the hypothesis in accordance with which they are framed is not exact, and cannot be depended upon for timing watches or determining our position on the Earth.

Magnitude of Nature.—The Scientific Method is applicable to the acquisition of knowledge of any kind, but it has been most used in the study of Nature. It is usual for each scientific investigator to confine himself to one department of Nature in which he finds the facts and tries to reason out the theories connecting them. Thus we are apt to form the impression that Physics, Chemistry, Astronomy, Geology, Geography, Meteorology, Biology are definite sciences, distinct from each other, dealing with different orders of facts which are accounted for by independent theories. These sciences do not completely cover the field of Nature as the coloured blocks of counties do the map of England. They traverse the field rather like the railway lines which radiate from London. The main line of each science is distinct and easily followed, but the branches interlace with one another in a complex manner, and though the network is very comprehensive, a mere fraction of the vast surface is after all covered with the lines of definite knowledge. Some

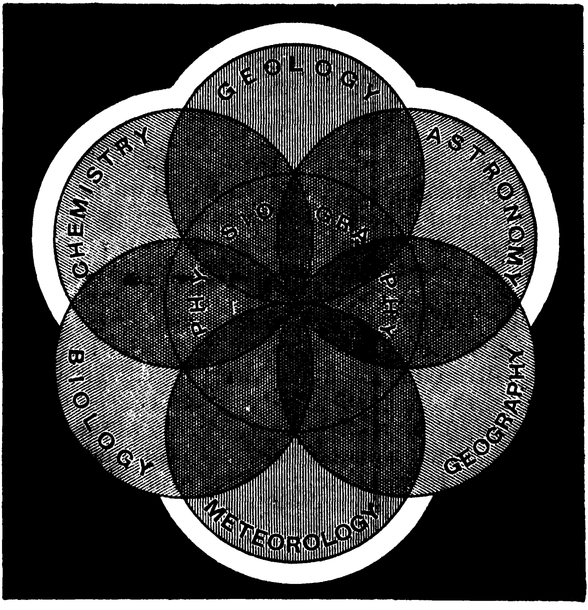

FIG. 1.—Inter-relation of the Sciences.

inter-relations of the sciences are shown in Fig. 1 by representing each as a circle cutting all the others, for on the outskirts of every science there are regions in which another science shares the explanation of phenomena. Chemistry, for example, is called in to aid astronomy in interpreting the spectra of the stars, to aid geology in explaining the composition of rocks, to aid biology in determining the changes of substance in living creatures. Physics or Natural Philosophy, represented as a white background in the diagram, in a sense includes every other branch of physical science, although portions of some, such as Biology and Geography, extend beyond its limits.

Physiography and the Special Sciences.—By division of labour the various parts of a watch are constructed by different workmen, and by the specialisation of science the different realms of Nature are explored by different investigators. In order to have a watch, however, the results of divided labour must be combined, and in order to have a just conception of the Universe the results of specialised research must be fitted harmoniously together. This is the function of Physiography, which has consequently a unique value in mental training, being at once an introduction to all the sciences and a summing up of their results. It enables a beginner to obtain a quicker insight into any of the special sciences and a fuller grasp of it, while at the same time a student versed in any one special science is enabled to appreciate the more fully its relation to all others and to the system of the Universe.

Physiography and Nature.—The natural Universe may be compared to a gorgeous carpet of rich design. In order to understand such a web we might follow out the pattern thread by thread. Selecting first a red thread of the weft, we notice how it passes above and below the threads of the warp, across the fabric and back again, to and fro until the end. Next a blue thread may be followed in the same way, and so with all the separate colours. The course of each thread has explained something, but the results of all must be brought together to give a complete explanation. In some such way each special science follows one of the threads of the Universe, but that thread is so interwoven with the clues of other sciences that a general knowledge of them all is necessary to understand the true bearings of any one. Pursuing the simile a step farther, we may note how one observer sees in the rich world-carpet nothing but a number of coloured threads intricately interwoven; the taste of another is so much gratified by the colour and design that he enjoys the beauty without thinking of the parts or the process; while a third loses sight of material and beauty alike in admiration of the genius of the designer and the skill of the craftsman. Thus the typical man of science, poet, and theologian look differently on the multiform unity of Nature, which has a true though different meaning for each.

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CHAPTER II

THE SUBSTANCE OF NATURE

Matter.—Diverse and innumerable as the things around us seem to be, the number of kinds is reduced greatly when they are tested by trying to destroy them. Only what cannot be annihilated is real, according to our definition. Tested thus, air, wood, marble, vinegar, to take a few random examples, appear unreal, for they can be produced and destroyed. Closer study shows that though burning destroys both wood and air it produces at the same time other things—ashes, water, carbonic acid, nitrogen—exactly equal in amount though different in properties. Vinegar and marble are both destroyed by mixing them, but other things—calcium acetate, carbonic acid, water—appear in exactly the same amount. So with all the things we see or feel, their properties and appearance can be completely changed, but the amount of substance that exists in them cannot be increased or diminished by any power which man has learned to wield. Substance is thus a real thing, of which air, wood, marble, vinegar and the rest are kinds. The term *Matter* is applied to everything, however diverse in appearance, which we see and touch, as Man is the term used to include every human being in the world. The difference between some kinds of matter is as slight and superficial as that between soldiers and chimney-sweeps; between other kinds it may be compared to that which separates Europeans from Negroes.

Energy.—There is another real thing which does not appeal so directly to our senses as matter does; a hundred years ago it was unknown and a long course of reasoning was necessary to convince investigators of its existence and reality. Nothing appears more readily produced or destroyed than motion, heat, or light. Motion is destroyed in a railway train by applying the brake, in a bullet by contact with the target. Heat can be destroyed by using it up in a steam-engine; the visible motion of an engine can be destroyed in turning a dynamo-electric machine; electric power can be destroyed in an incandescent lamp; light can be destroyed by allowing it to fall on a black surface. Hence none of these things is real in itself. But when motion is stopped in a train heat is invariably produced, the wheels sometimes becoming red-hot. When heat is destroyed in a steam-engine, visible motion is produced; when motion is destroyed in a dynamo-electric machine, electric power is produced; when electric power is destroyed in a lamp, light is produced: and when light is destroyed by falling on a black surface, heat is produced. More than this, the amount of heat, motion, electric power, light, produced is the precise equivalent of what is destroyed in making it. All are capable of doing work of some kind, and this power of doing work can neither be created nor destroyed, its amount can neither be increased nor diminished. *Energy* is the name given to this real thing.

Matter and Energy in Nature.—Besides matter and energy nothing has been proved to have an independent existence. The whole of Nature may be held to consist of the two grand parts, that which works and that which is worked on. The two are quite inseparable, for work of every kind has been proved to involve of necessity motion through a large or a small space in straight or curved lines, and motion is incomprehensible except as some piece of matter moving. It is only through matter that we recognise energy, and only through energy that we recognise matter.

It has been proved in some cases, and is probably true in all, that the properties which distinguish different kinds of matter from each other are due to the different amounts of energy with which they are associated.

Matter is that which occupies space. This definition is in many ways the most satisfactory; but although attempts to say what matter is have been made by philosophers in all ages, no really sufficient definition has ever been arrived at. Matter has also been defined as that which can be perceived by the senses.

Mass is the term used to denote quantity of matter. Thus when the mass of the Sun is spoken of as being 330,000 times that of the Earth, it is meant that the Sun contains 330,000 times as much matter as the Earth contains. Mass is usually measured out by the balance, and it is common to speak of the mass of any portion of matter as its *weight*, although on the same principle we might speak of a man's health as his appetite. The standard unit of mass in the British Empire and the United States is the pound; in almost all other civilised countries it is the kilogram.

Volume and Density.—*Volume* is the amount of space occupied by a body, and if matter were of one kind and always in the same state, the same mass would always fill the same volume. But matter exists in many forms, and if, for example, we compare together charcoal, lithium, coal, granite, arsenic, lead, and platinum, we find that the same volume contains very different quantities of matter. The mass of a cubic inch of platinum is nearly twice that of a cubic inch of lead, four times that of arsenic, eight times that of granite, sixteen times that of coal, thirty-two times that of lithium, and sixty-four times that of charcoal. So that these parcels of matter are packed with different degrees of tightness, as much as is present in 64 cubic inches of charcoal being packed within the limits of 1 cubic inch of platinum. The mass contained in a unit of volume is called its *density;* thus in the list given above the density of each substance mentioned is nearly twice that of the preceding. The unit of density universally employed is that of water, and calling this 1 the densities given above run:—

Charcoal.	Lithium.	Coal.	Granite.	Arsenic.	Lead.	Platinum.
0·34	0·59	1·33	2·70	5·96	11·36	21·53

The density of each kind of matter is very distinctive; that of quartz, for example, is 2·6, that of the diamond 3·5; and by means of this difference diamond buyers at once detect any attempt to pass off a piece of quartz as a rough diamond. The term *specific gravity* is often used to express the ratio of the density of substances to that of water.

Form.—The form which different kinds of matter assume varies greatly, and can be easily changed. Pure kinds of matter, that is to say, elements and compounds—metallic bismuth, alum, or quartz, for example—when allowed to solidify or separate out of solution frequently assume shapes of beautiful symmetry, and these definite forms are spoken of as *crystals.* Mixtures, and some pure kinds of matter, have no special form naturally, but occur as they were moulded in the cavity or vessel containing them, or as they were broken off from larger pieces. These are often spoken of as *amorphous* or formless. The forms of crystals are so characteristic that the minutest trace of some substances may be recognised by their appearance under the microscope.

Angular Measurement.—In considering the form and position of bodies regard must be had to the properties of space, and especially to the nature and use of angles. An angle is the inclination of two lines which meet at a point, and it may be measured by a certain definite amount of turning done by a line; the angle APB in Fig. 2 is the amount of turning in a line from the position PA to the position PB. If the line PA were drawn on a piece of card pivoted to a table by a pin through P, and if it were made to turn completely round, as shown by the arrow, until it came back to its original position, the end A would have pointed in turn all round the room; or if the table were in the open air, all round the horizon. The space of a whole turn is divided into 4 equal quadrants or quarters, each of which is called a right angle, and the amount of turn in a right angle is divided into 90 equal steps called degrees (°), each degree being the 360th part of a whole turn. Every degree is subdivided into 60 equal parts called minutes (′), and each minute into 60 parts called seconds (″). An angle of 1″ is thus simply a short name for "the 1,296,000th part of a whole turn," and small though this is, $\frac{1}{10}$ of a second or less can be measured in fine instruments. The amount of turning from the horizon or sky-line of a plain to the zenith or point directly overhead is a right angle or one-quarter of a complete turn, *i.e.* 90°. Degrees, minutes, and seconds are thus simply fractions of the unit which is a turn; and a turn is the same whether the turning line sweeps round the horizon, the Earth's equator, or a watch dial.

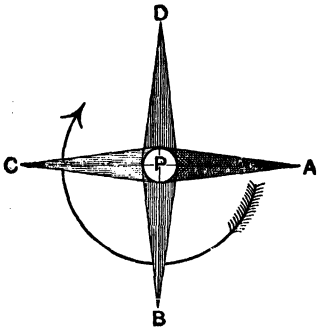

FIG. 2.—Four Right Angles.

Position by Angles.—If we fix points from which to begin the reckoning, two sets of angles will enable us to define the position of any object on a sphere, or hemisphere, such as the sky. In the case of a star, for example, by taking the north point of the horizon as a zero, one first measures the number of degrees, minutes, and seconds of turn until directly under the star, noting in which direction (toward east or west) the turn is taken. Then from the horizon at that point one measures the number of degrees, minutes, and seconds of turn toward the zenith to the star. Angular distance round the horizon is called the azimuth of a point; angular distance toward the zenith from the horizon is called the altitude. The instruments most convenient for measuring angles are described in Appendix I.

Measurement of Distances by Angles.—Any one can observe in passing a church clock that if, when standing directly opposite it, he sees the long hand pointing exactly to XII, he may by going a little distance to one side see it to be a minute or so before, and by going the same distance to the other side a minute or so after the hour. This is because the clock hand is nearer us than the dial plate, and when we look at it from different points of view it appears to fall on different parts of the dial. By measuring the angles, and the distance between the two points of observation, it is possible to calculate the distance of the object by trigonometry—the part of mathematics dealing with triangles. Suppose that in Fig. 3 the distance from A to B, which is called the base-line, is 100 yards, and that the angles PAB and PBA are measured, then since all the angles of a triangle are equal to two right angles, the angle at P can be got by a simple subtraction, and an easy calculation would give us the distance of P from the eye. The more nearly equal the three angles of APB, the more accurately can this distance be found. For example, from the same base-line the angles to the hand of a much more distant clock would differ much less from right angles; the angle at Q would be so minute that the least mistake in measuring the two large angles would put the calculation all wrong. In this illustration the angle at P might be measured without using

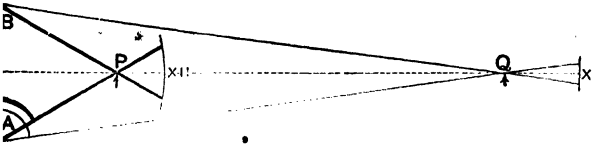

FIG. 3.—Angular Measurement of Distance. AB, Base-line; P, Q, vertical angles.

an instrument by noting the amount of displacement of the long hand of the clock on the dial as viewed from A and B. In the more distant clock the displacement might be too slight for the eye to detect.

Exclusiveness is a term descriptive of the way in which matter occupies space. It means that when one portion of matter is in a certain space no other portion of matter can be in the same space. The fact that a quantity of water can be absorbed by a sponge without much increasing the volume is no argument against this statement, for the water occupies only the cavities between the sponge fibres. The particles of many kinds of matter are packed loosely together so that vacant spaces or pores occur. Porous bodies, like unglazed earthenware, sandstone, and charcoal, apparently allow air or water to pass through them; really, however, the fluid passes through the otherwise empty pores. The exclusiveness of the space-occupation thus holds good for the smallest particles of matter only. The term *impenetrability* is often used for this property.

Stresses and Strains.—When the form or volume of a body is altered the body is said to be *strained*, and the set of forces which produces a strain is called a *stress*. Stresses act always in two opposite directions, either as a push or a pull. *Rigidity* is the resistance that a solid body offers to shearing stress. Extremely rigid substances, such as steel, require the action of powerful stresses in order to change their form; while less rigid substances may be readily deformed or strained, as a rod of lead is bent or a piece of sandstone pounded into dust. When uniform pressure is applied all solid substances, and still more all liquids and gases, are reduced in volume, the matter in them being compressed into smaller space and the density being of course increased. The amount of compression which the same pressure effects is called *Compressibility* and it differs in various kinds of matter, being greatest of all in gases. The tendency of a body to recover from strain and to return to its previous form and volume when the stress ceases to act is termed *Elasticity.* A steel watch-spring is said to be elastic, because after being coiled up tight it returns to its former size and shape. Air is said to be elastic, because when it has been compressed and the pressure is removed it returns at once to its previous volume.

Gravitation.—*Every portion of Matter attracts or tends to approach every other portion of Matter in the Universe with a force proportional to the masses and inversely as the square of the distance.* This is Newton's Law of Universal Gravitation, and is established beyond any doubt, within the solar system, although the true nature of gravitation remains unknown. The greater the mass of two bodies, the more strongly do they attract; if the mass of one is doubled, the attraction is doubled; if the mass of each is doubled, the attraction is increased fourfold. The nearer they are the more strongly do they attract in the proportion that halving the distance increases the attraction fourfold, reducing the distance to one-third increases the attraction ninefold. Fig. 4 illustrates this law of attraction.

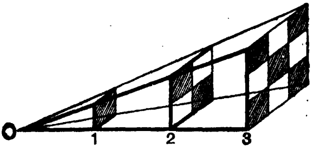

FIG. 4.—Inverse Squares. The gravitational force of O acting on the square at 1, is spread over four times the area at 2, and nine times the area at 3, so that the force acting on a unit square at 3 is $\frac{1}{9}$, and at 2 is $\frac{1}{4}$ of that at 1.

The meaning of "Down."—If two distant bodies equal in mass could be left free to follow the attraction of gravitation, they would approach each other and meet midway. But if one of the distant bodies had a much larger mass than the other it would move a shorter distance, because the result of attraction is to give the same amount of motion or momentum to each. If one body is very large and the other very small, the small body seems to fall to the larger, while the latter does not apparently leave its place. This is the case of a stone outside the Earth's surface. It falls directly toward the centre, and the word "down" is used to designate this direction. The movement of the Earth to meet the stone is so slight that it cannot be detected, nor very easily expressed by figures. Still the attraction of gravitation is equal and opposite, the stone attracting the Earth as much as the Earth attracts the stone.

Weight.—The attraction of the Earth would draw an external body down to the centre, but the rigidity of the Earth's crust resists distortion. Those parts of the surface which possess no rigidity (the oceans) allow any body denser than water to pass through, or sink in obedience to the pull of gravity until it reaches the solid crust below. The pull of gravity which is counteracted by the push of rigidity is of course greater for greater masses, and the amount of the pull in any case may be measured by pulling against it. Weight is the name given to the measure of the pull of the Earth upon another body. At any definite distance from the Earth's centre the weight of a body is proportional to its mass, and hence it is that when we want one pound mass of tea we ask for one pound weight. If any mass is removed to a greater distance from the Earth's centre the pull upon it is diminished, or, in other words, its weight is less; if it is brought nearer the centre (without passing inside the Earth) the pull upon it is increased, or the weight is greater. Weight, or "Earth-pull," is measured by means of the spring-balance or by the pendulum. On account of the uniform pull of the Earth's gravitation at the same distance from the centre, liquids, which have no rigidity, assume a level surface, or rather a surface concentric with that of the Earth. One of the necessary conditions for equilibrium in a liquid is that all points in the same plane are subject to the same pressure, hence the level of water in a series of connected vessels is always the same. Hence also if the height or the density of part of a body of liquid is altered equilibrium is destroyed, and the liquid moves under the influence of gravity until it again becomes homogeneous and of level surface. Gravitation is a property which affects every kind of matter alike, and it binds together the great masses of the Universe into a firm and flexible whole.

Cohesion.—When the distance between particles of matter is very minute—too small to be measured—the force of attraction is very great, and binds the particles together very firmly. In this case it is called cohesion. It is by the powerful attraction of particles of matter at very minute distances that a stone is wetted or covered with a thin liquid film when dipped in water. These forces are also shown at work when a liquid rises in a narrow tube, or in a porous body like a sponge, a lump of sugar, or a piece of sandstone. This raising of liquids is called *capillarity* because it is best seen in tubes whose bore will just admit a hair, but it is quite visible on the sides of a tumbler. Another manifestation of the same force is seen in *surface tension*, or the tendency all liquid surfaces have to become as small as possible. A small portion of a liquid when thrown off as a drop shrinks into a little sphere, because a sphere has the smallest surface possible containing a given volume. A soap-bubble blown on the wide end of a glass funnel contracts and creeps up to the narrowest part of the tube when left to itself. Surface tension accounts for such phenomena as the rapid spreading of a film of oil over a wide surface of water, and for the gyrations of a piece of camphor floating on clean water.

Analysis and Synthesis.—If we wish to find out for ourselves of what parts a piece of mechanism, such as a watch, is composed, we must begin by unloosening the parts from one another and taking the watch to pieces. So when we wish to find of what parts a piece of matter, such as a rock, is made up, we must unloosen its parts and take it to pieces. This process is called by the Greek name of *analysis*. There is another process sometimes employed: we might imagine a watch so strongly made that it could not be taken to pieces, but if we had seen the parts put together to make it, we would know of what it was composed.

This putting together is called *synthesis*, and the process is sometimes used for investigating kinds of matter.

Mixtures.—We may take a piece of *granite* as typical of a pure kind of matter which is easily recognised by its characteristic appearance. On examining it with the eye we see that it is made up of three different substances. One of these is clear and glassy, breaking with a sharp edge, and hard enough to scratch glass. It is called *quartz*. Another is milky and opaque, whitish or pinkish in colour, too soft to scratch glass, and when it is broken it splits into regular smooth-sided blocks of similar shape. It is called *felspar*. The third ingredient is silvery or black in appearance; it forms flakes which are soft enough to be scratched by the nail, and flexible, splitting up into thin transparent scales. It is called *mica*. Granite, then, is a mixture of quartz, felspar, and mica, and the proportion of each ingredient varies in different specimens. In a mixture each ingredient retains all its own properties, and so can readily be recognised and separated. A mixture of sand, salt, and sawdust, for example, could be separated by throwing it into water, in which the sawdust would float, the sand sink, and the salt dissolve.

Compounds.—Quartz, felspar, and mica may be examined as closely as the most powerful microscope allows, but no sign of any of them being a mixture will appear. Every one part of quartz is exactly like every other. Quartz, which is also called silica, can be separated into two substances by means of certain processes explained by the science of chemistry. One of these substances is a brown opaque solid called *silicon*, the other an invisible odourless gas named *oxygen*. Silica is not called a mixture but a compound, the distinction of which is that the components lose all their characteristics and unite to form a homogeneous substance, different in its properties from any of the components. For example, the metal magnesium is a tough lustrous solid; oxygen is an invisible gas present in the air; the compound resulting from their union is a soft snow-white powder. The composition of compounds is always exactly the same, the same proportion of each component being always present. Silica is invariably composed of 14 parts by mass of silicon and 16 of oxygen; magnesia always contains 24 parts of magnesium and 16 of oxygen. The proportional numbers, used to express the way in which simple substances unite, are called "atomic weights."

Analysis of Granite.—Felspar may be analysed into silica, alumina, lime and potash, each one of which is in itself a compound; and Mica can be analysed into silica, alumina, magnesia, potash, water, and iron oxide, all of which are compounds. The ultimate components are termed *elements*, of which some, such as oxygen and silicon, are classed as non-metals, the others as metals; but this classification is somewhat vague.

GRANITE.

QUARTZ.		FELSPAR.		MICA.	
Silica	Silicon. Oxygen.	Silica .	Silicon. Oxygen.	Silica . .	Silicon. Oxygen.
		Alumina	Aluminium. Oxygen.	Alumina . .	Aluminium. Oxygen.
		Potash .	Potassium. Oxygen.	Potash . .	Potassium. Oxygen.
		Lime . .	Calcium. Oxygen.	Magnesia .	Magnesium. Oxygen.
				Iron Oxide	Iron. Oxygen.
				Water . .	Hydrogen. Oxygen.

Acids and Bases.—Two classes of compounds require to be specially mentioned. The non-metal oxygen when it unites with a metal produces a compound called a *basic oxide*, and this is the case whether we consider the gaseous metal hydrogen, the liquid metal mercury, or any of the solid metals such as magnesium, calcium, or potassium. When oxygen unites with another non-metal, such as carbon, silicon, or sulphur, it produces an *acid oxide*. The main characteristic of basic oxides and acid oxides is that when brought together they unite to form more complicated compounds called *salts.* A certain amount of each acid oxide unites with a certain amount of each basic oxide to form a compound showing neither acid nor basic properties, but in many cases an additional definite amount of acid or of basic oxide takes part in the compound which then shows a more or less distinct acid or basic nature. Other non-metals, such as sulphur and chlorine, unite with metals to form compounds or salts termed sulphides and chlorides. Energy in the form of light or heat is usually given out when elements combine, and an equal amount of energy must be used up on the resulting compound in order to decompose it. When much energy is involved in the transaction the compound is said to be a firm one.

Elements.—The process of analysis was believed until recently to cease when we come to oxygen, silicon, aluminium, etc., and, as these were supposed to be incapable of being split up into other kinds of matter, hence they are called the simple substances or elements. There are about ninety elements known to chemists, but those which have been enumerated, together with carbon, appear to make up by far the greater part of the mass of the Earth. Professor Prestwich gives the accompanying estimate of the proportion in which each of the common elements occurs in the Earth's crust.

ELEMENTS OF THE EARTH'S CRUST.

Oxygen	50·0
Silicon	25·0
Aluminium . . .	10·0
Calcium	4·5
Magnesium . . .	3·5
Sodium and Potassium .	3·6
Carbon, Iron, Sulphur, and Chlorine	2·4
All others . . .	1·0
Total . .	100·0

Transmutation of Elements.—For centuries the alchemists firmly believed that one element could be turned into another, and hundreds of men spent their fortunes and their lives in seeking the "Philosopher's Stone" which would bring about the magic change of lead to gold. In more recent times, as the knowledge of the properties of matter has increased, the possibility of such a change has been generally conceded; and it has been discovered that those elements which show a particular property known as radio-activity are, in fact, undergoing transmutation into other elements. Thus uranium produces radium and helium, and it is believed that radium ultimately produces lead. The rearrangement of the particles with regard to each other in one kind of matter produces great changes in the outward properties. Charcoal and diamond are each a form of pure carbon, and each has been changed into the other by the action of energy in certain ways. Hence it appears possible that the separate elements may themselves be simply different groupings of the one real thing we call matter, associated in various ways with different amounts of the other real thing we call energy.

The Periodic Law.—Elements are roughly classed into metals and non-metals, but there are intermediate ones which it is not easy to assign to either division. A more natural grouping was discovered by Mr. Newlands in England, and Professor Mendeleieff in Russia, and is known as the Periodic Law. This states that if the elements are arranged in the order of the mass of their smallest particles, *i.e.*, their atomic weight, they will fall into nine groups of about twelve elements each, and the first, second, third, etc., element of each group bears a strong family resemblance to the first, second, third, etc., of each of the other groups. Some of the groups have gaps, ninety-odd elements being as yet known; but the atomic mass, the density, the melting temperature, the colour and the nature of the compounds it would form with known elements can be calculated and predicted for each of the elements which are absent. Names have even been given to these hypothetical elements, and one after another the elements have subsequently been discovered by chemists and found to correspond exactly to the prophetic description. This fact was the strongest confirmation of the truth of the Periodic Law. If the figures known to chemists as "atomic weights" really correspond to the mass of the atoms of each element, as there is reason to believe that they do, the chief difference between the elements may consist in the fact that their smallest particles contain different amounts of matter; the extreme cases are uranium and hydrogen, the mass of the atom of the former being 240 times that of the latter. We could imagine a great rock to be quarried into blocks of ninety-six definite sizes, the smallest being only $\frac{1}{240}$ of the largest, and shiploads of these cut and squared stones might be sent to a country where tools were unknown. There people might use the stones in building houses, but would be unable to change any one size into another until they invented the proper tools. They might be supplied only with sixty or seventy of the sizes, but by studying the weights of these and seeing the order in which they ran they might predict the existence of intermediate sizes. As they could not in the absence of tools change the form or size of the blocks, though recognising their unity of composition, they would look on them as unalterable elements in their building. Similarly modern chemistry has enabled us to understand how it is possible for the elements to be merely separate parcels of matter which may be broken up and rearranged when the proper tools are found.

Structure of Matter.—Any element or compound appears perfectly homogeneous under the most powerful microscope, but the investigations of scientific men prove that there is a limit to homogeneity. The smallest particles of which matter consists are far too minute to be visible directly—the smallest visible speck is calculated to contain more than 50,000,000 of them. By careful experiments and ingenious reasoning Lord Kelvin showed that matter is made up of particles so small that if a little cube 1 inch in the side were magnified until it was 8,000 miles in the side, neighbouring particles would be 1 inch apart; in other words, there are about 500,000,000 particles in the length of an inch. The study of chemistry has shown that each particle must, in almost every case, consist of at least two, but probably many, parts called atoms which cannot exist separately but always form groups. The atoms of every element are different from those of every other element; but each atom of any element is exactly like all the other atoms of that element. In recent years it has been recognised that the "atom" of the chemist is not permanent, but is subject to changes, and not indivisible but composed of numerous smaller corpuscles of two kinds. The researches of Sir J. J. Thomson and other physicists have proved that the chemical atom has a structure resembling a miniature solar system. There is a minute nucleus carrying a permanent charge of positive electricity around which circulate a series of electrons which are still more minute and each carries a permanent charge of negative electricity. The energy (p. 32) of movement in the electrons of each atom is very great, and Sir Oliver Lodge suggests that the electrons themselves may be minute vortices in the ether (p. 39), so that the universe consists of ether and energy, the mutual action of which gives rise to matter. He thinks that matter may possibly be called into existence by the action of radiant energy on the ether, and that it can be resolved again into radiant energy in certain circumstances. Whatever the nature of matter may be we are sure that the laws expressing its relation to energy hold good so far as all the phenomena described in this book are concerned.

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Sir W. Ramsay, *Modern Chemistry*, 2 vols. Dent and Co.

CHAPTER III

ENERGY, THE POWER OF NATURE

Energy is the power of doing work. Work, in the scientific sense, is any change in the position of portions of matter brought about against resistance. Change of position implies motion, and thus work may be spoken of as the moving of matter. Lifting water from a well by means of a bucket and rope is work against the resistance of gravity; tearing a piece of paper is work against the resistance of cohesion; pulling a piece of iron from a magnet is work against the resistance of magnetic attraction, and so on. Work is measured by the resistance overcome, and the distance through which it is overcome; the resistance usually chosen for this purpose is weight or the pull of the Earth on matter in consequence of gravitation. In English-speaking countries the unit of work usually adopted is the foot-pound, the amount of work necessary to raise 1 lb. weight to the height of 1 ft. The work of raising 10 lbs. 1 ft. is 10 foot-pounds, and the work of raising 1 lb. 10 ft. is 10 foot-pounds also. The work a man of 150 lbs. weight does in climbing to the top of a mountain 10,000 ft. high is 1,500,000 foot-pounds, as much work as lifting 167 tons of coal from the ground up to carts 4 ft. high.

Newton's first Law of Motion expresses the property of Matter called *Inertia*, thus: *All bodies remain in a state of rest or of uniform motion in a straight line except when compelled by some external power to change that state.* On the Earth friction is always at work retarding motion. A train moving at 60 miles an hour on a smooth level railway only requires the engine to give out enough energy to overcome the resistance of the air and the rails ; when that is done the train, however great its mass, continues to move with undiminished speed. When it has to be stopped quickly, shutting off steam from the engine is not enough ; great resistance has to be introduced by means of brakes which convert the energy of motion rapidly into heat. The energy expended in setting a mass in motion is preserved in the moving mass when there is no external resistance, and returned unaltered in quantity when the motion is stopped. The amount of motion in a moving body is called its *momentum*, and is measured by the mass and the velocity together. A mass of 1 lb. moving with a velocity of 1000 ft. per second has the same momentum as a mass of 1000 lbs. moving at 1 ft. per second.

The Gyroscope illustrates the first law of motion. The most familiar form consists of a heavy leaden wheel turning on an axle in a brass ring. The inertia of the fly-wheel requires to be overcome by imparting a considerable amount of energy to it by means of a cord and a strong pull of the arm ; once set in motion it would never stop but for the friction of its axle and of the air. A gyroscope in rotation behaves differently from one at rest. When the experimenter takes it by the stand and attempts to change the direction of its axis of rotation it seems to have a will of its own ; it strongly resists any change of position, although when the fly-wheel is at rest its axis may be easily turned in any direction. In the fly-wheel itself there is a struggle going on ; the particles tend to move in straight lines, and it is only the attraction of cohesion that compels them to move in a circle. In factories grindstones are sometimes made to rotate so fast that they burst ; the tendency of the parts to move in straight lines being too great for the cohesion of the stone to counter-balance. The tendency of a body moving in a curved path to follow a straight line tangential to the curve is often called *centrifugal force.*

Work against Gravity.—In employing energy to overcome weight there seems at first sight to be a real loss unlike the case of inertia. An exhausted mountaineer, on reaching the summit referred to on p. 32, might ask, "Where are my million and a half foot-pounds of energy?—are they not lost for ever?" If the mountain were precipitous on one side the climber could answer his question by an experiment, not on his own person, but on a block of stone of equal weight (150 lbs.). Such a block in virtue of its elevated position has acquired the power of doing work. The attraction of the Earth draws the stone downward, and once allowed to fall it moves faster and faster until it strikes the ground with enough energy of motion to do 1,500,000 foot-pounds of work. This energy in a real case would be expended partly in heating the air during descent, and partly in shattering the stone and heating the fragments and the ground. The amount of energy expended and the ultimate form assumed are the same if the stone rolls down a slope as if it falls vertically, and the same for 150 lbs. of water flowing in a stream through the same difference of level.

Energy of Motion.—The faster a body is moving the more work it can do, *i.e.* the more energy it contains. A leaden bullet thrown against a man by the hand might inflict a painful blow, projected from a sling at the same distance it would produce a serious bruise, but fired out of a gun it would pass right through the victim. The greater the velocity of the bullet the greater is its power of doing work. But a small bullet striking a steel target is stopped, while a large projectile, though moving at the same speed, breaks its way through; hence the greater the mass in motion the greater is its energy. When the mass of a moving body is doubled its energy is doubled, but when the velocity of a moving body is doubled the energy is increased fourfold. For example, a small river flowing at 6 miles an hour could do as much work in turning mills as a river four times the volume flowing at the rate of 3 miles an hour. This is expressed in the form of a Law—*Energy of motion is proportional to the moving mass and to the square of the velocity.*

Potential and Kinetic Energy.—Energy of position may be called an expectant, energy of motion an active power of doing work; or, to use the usual terms, the former is potential, the latter kinetic. The raised weight or coiled spring of a clock contains potential energy, which is gradually converted into the kinetic energy of moving wheels and hands. The simple *Pendulum* consists of a heavy ball hung by a thin cord. Its practical value depends on the fact that if the length of the cord does not change, the ball swings from one side to the other in exactly the same time through any small arc. If the ball is pulled to one side to A (Fig. 5), since the cord does not stretch A is more distant from the Earth's centre than is B, and when let go its weight makes it swing back toward B. At A the pendulum has a certain amount of potential energy on account of its raised position, and as it falls it loses that potential energy, gaining instead kinetic energy, so that it passes the point B in the full swing of its active movement. The power immediately begins to do work against gravity in raising the ball to C, and the ball rises more and more slowly as its kinetic energy is being used up until at C, nearly as high as A, it comes to rest. Here it possesses nearly as much potential energy as it did at A, and so swings back again. The swings become shorter, and finally it comes to rest only because the friction of the air and of the cord on its point of attachment gradually changes all the energy into heat.

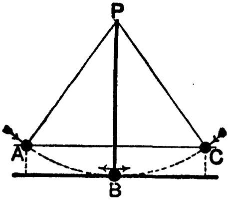

FIG. 5.—Swing of a Pendulum. A, C, Highest points of swing; B, lowest point.

Conservation of Energy is the term employed to denote the fact that the total amount of energy in

Nature, as in the case of a frictionless pendulum in a perfect vacuum, never varies; that energy like matter can neither be created nor destroyed. Many clever mechanicians have endeavoured to find the *Perpetual Motion*, by which a machine when once wound up and set agoing would not only go on for ever, but would do work as well. In January 1890 an advertisement in *The Times* stated that the discovery had been made, and the inventor wanted pecuniary help to complete it, but this like all the efforts of all the centuries was a failure. Knowledge of the laws of energy would have saved the advertiser much lost time and useless trouble. We know that if a machine could run without resistance it would go on for ever at the same rate in virtue of inertia if energy is once imparted to it. But if a machine could not only keep going but set looms in motion as well, energy must be created at every turn, and experience proves that this has never taken place. If energy be a real thing the Perpetual Motion is impossible. Energy is always undergoing transformation, visible motion, magnetism, electrical power, heat, and light being some of the many forms which it assumes. But Nature says sternly and unmistakably, "Nothing for nothing." No form of energy can be obtained without paying an exact equivalent in some other form.

Invisible Energy.—Work can be done and potential energy stored in separating atoms as well as in climbing mountains; and the union of the separated atoms reconverts potential to kinetic energy as truly as the downward rush of an avalanche. When a stone strikes the ground its energy of motion as a whole is changed into energy of motion of its parts, which we recognise as heat. Three kinds of motion occur both on the great scale, perceptible to the eye, and on the small scale, discoverable by observation and reason. These are simple *translation*, like the movement of falling stones or of the darting particles of gases; *wave motion*, like the undulations of the sea or the vibrations producing light; and *vortex motion*, like whirlpools in tidal streams or the disturbances we recognise as magnetism.

Wave-motion.—Every elastic substance can propagate wave-motion. This motion consists in one particle moving through a comparatively short path and returning to its previous position, after passing on its energy of motion to another particle which also moves a short distance and returns. Waves of to-and-fro or up-and-down motion occur in solids and liquids; and waves of alternate compression and expansion occur in gases. Waves are measured by the distance between similar parts of successive waves. The distance between crest and crest (CC in Fig. 6) or between trough and trough (TT) of waves in water, or between succeeding maxima of compression or of rarefaction in waves of air, is spoken of as the wave-length. The amplitude of a wave is the distance from crest to trough (C′T), or the difference between maxima of compression and rarefaction.

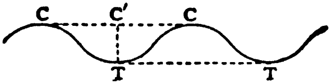

FIG. 6.—Wave-motion. C C, Crests; T T, troughs.

Sound.—When a wave of alternate compression and rarefaction of air strikes the ear, it produces the sensation of sound; the more rapid the vibration and shorter the wave-length the shriller is the sound, but neither very short rapidly vibrating waves of air nor very long slowly vibrating waves affect the ear at all. The greater the amplitude of an air-wave, the louder is the sound. Waves of compression and rarefaction pass through the air at the rate of about 1100 feet per second when the temperature is 32° F., and travel a little over 1 foot per second faster for every degree that the air is warmer. Sound-waves pass through water four times as fast, and through solids many times faster than through air. Air is set into wave-motion by any body that is vibrating as a whole or in segments, such as a tuning-fork, a stretched string, or a column of air in a pipe. A tuning-fork when made to vibrate sets up air-waves that produce the sensation of a particular musical note in the ear ; if that tuning-fork is at rest, and is struck by air-waves of the same kind as those it can set up, they transfer their energy to the fork and start its vibrations. All other air-waves, longer and shorter alike, pass by with but slight and transitory effects, and, stated generally, the law holds that *Bodies absorb vibrations of the same period as those which they give out.* When certain notes are sung, or struck on a piano, glass globes in a room absorb the particular waves which they would set up if struck, and ring in response to them.

Molecular Vibrations are the minute movements of the smallest particles of bodies, either as a quivering of the particle itself or as quick oscillations to and fro. As long as there is any kinetic energy associated with a portion of matter the particles will be in motion. The amplitude of the oscillations in solids is very slight, not sufficient to overcome the resistance of cohesion. However large a body may be, its particles will in time come to oscillate at the same rate throughout if not interfered with, any more quickly-moving particles passing on some of their energy to their more slowly-moving neighbours. The process of passing on and equalising the rate of molecular vibration is called *conduction*, and takes place, although more slowly, in liquids and gases as in solids.

Radiant Energy.—As the vibrations of bodies, as a whole, set up waves of various length in air which may travel to a distance, and some of which are capable of impressing the ear, so the invisible vibration of the particles of bodies sets up waves of radiant energy which travel to a distance, and some of which impress the senses. The quiverings of particles are very complex, and the particles of each kind of matter seem to quiver and oscillate in a way of their own, setting up waves which, although excessively minute, are far more complex than those of sound. There is much difficulty in understanding how the waves of radiant energy travel, and it is assumed that a very remarkable kind of matter called the *Ether* fills all space, and penetrates freely between the particles of ordinary matter. It is so fine that it offers no perceptible resistance to the movement of the planets through it, or to the movements of the particles of matter; but it is so elastic that it passes on the smallest and swiftest undulations. The undulations travel in straight lines through the ether at the rate of over 186,000 miles per second, and all waves in the ether whatever their length or amplitude travel at the same rate, about a million times as fast as the waves of sound in air.

Reflection and Refraction.—When the waves of radiant energy reach a surface through which they cannot pass, they are turned into a new path, either directly backward or at a definite angle to their former direction. Sound-waves meeting an obstacle are *reflected* in the same way, giving rise to echoes, and so are the little ripples of a water surface on meeting a straight line of cliffs. When the ripples of the sea pass among a number of half-covered stones their onward path is changed in direction, each little undulation being bent from its course by the obstacle it meets. Similarly, when a ray of radiant energy passes from one medium into another of different density, *e.g.* from the ether into air, or from air to glass, the undulations are diverted by the particles of matter, and the ray is bent or *refracted.* Radiant energy is made up of many different vibrations; some are comparatively long and are slow in their vibration, others are very short and much more rapid. The short quickly-vibrating waves are most bent from their straight path by passing into a different medium, and are therefore said to be most refrangible. It is evident that if a beam of radiant energy, in which each ray corresponds to a definite wave-length, travelling straight on, enters a denser medium, the separate rays will be spread out like the ribs of a fan, those of the shortest waves being most turned from the straight line, those of the longest waves least.

The Spectrum.—When the undulations which come from an intensely vibrating solid enter a triangular glass prism (Fig. 7, P) through a narrow slit, they are spread out by refraction and arranged side by side in perfect order from those of shortest wave-length, *v*, to those of longest, *r*, forming a *spectrum*. The waves shorter than $\frac{1}{67000}$ of an inch have a peculiar power of affecting certain substances and producing chemical changes, but they have no effect on the senses. The waves between $\frac{1}{67000}$ and $\frac{1}{28000}$ of an inch in length (*vr*) affect the sense of sight through the eye, producing the sensations of light and colour, hence they are termed light-waves. Waves of longer wave-length set the particles of bodies in vibration when they fall on them; they are invisible to the eye and are known as heat-waves. The shortest of the light-waves (*v*) produce the effect of violet light, longer ones (*b*) blue, still longer (*g*) green, longer yet (*y*) yellow, and the longest that produce any effect on the eye (*r*) red. Thus when one looks at a glowing solid body through a spectroscope, an instrument containing one or more prisms, the colours red, yellow, green, blue, violet are seen ranged in a row as in the rainbow (Fig. 8, which gives a detailed view of the range *vr* of Fig. 7), but the eye sees nothing of the short wave-length rays beyond the violet, nor of the relatively long wave-length rays beyond the red. Very much longer waves can be detected by their electro-magnetic action, and these are utilized in wireless telegraphy and telephony.

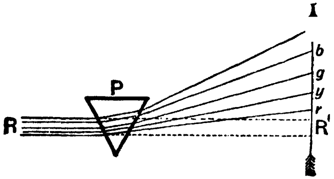

FIG. 7.—Prismatic Refraction. RR', Straight path of light ray; R*vr*, refracted path.

Radiation and Absorption.—The different wave-lengths of sound in air correspond to different musical notes, the different wave-lengths of light in the ether to different colours. The molecules in the vapour of each of the elements vibrate in a way of their own when set in motion, and produce waves in the ether of certain definite lengths. Sodium vapour, for example, when intensely heated sets up only rays the wave-length of which is $\frac{1}{43000}$ of an inch, and these produce the sensation of yellow light in the eye. A spectroscope sorting out the light from glowing sodium shows only a strong double yellow line (D in Fig. 8). The molecules of calcium vapour produce several distinct kinds of quivering, originating rays corresponding to definite colours of light. The same is true of all the other elements; the spectra of the radiant energy sent out from them are distinctive in every case. But, as in the case of sound, bodies absorb the same kind of radiations as they emit. If a beam of white light, which includes rays of all wave-lengths, is passed through sodium vapour, the particles of sodium are set vibrating by the waves $\frac{1}{43000}$ of an inch in length, and the energy of these waves is absorbed, so that when the beam is examined by the spectroscope, and the rays are spread out side by side, the peculiar double yellow ray is missing and in its place there is a blank or black line. The same is true with the vapours of all the other elements, the particular waves absorbed differing in each case. *Spectrum Analysis* is a term used to describe the discovery of the elements whose vibrations give out a certain kind of light. It is not only analysis or unloosening; it is also a method of seeing through a compound when taken apart by the action of heat. However distant a body may be, if it gives out light, the light tells its own tale as to the matter whose quiverings sent waves through the ether, and as to any other kinds of matter which may

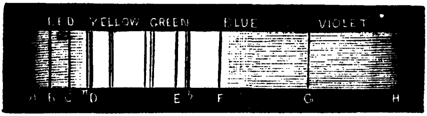

FIG. 8.—Diagram of the Solar Spectrum, showing the Order of Colour and the Position of the Principal Absorption Lines.

have exercised absorption on it in intermediate space.

Light and Colour.—The light which is produced when waves of radiant energy corresponding to all or nearly all the wave-lengths that affect vision strike the eye together is white. When waves of light fall upon any object, some are absorbed and others are reflected; the report these reflected rays convey through the optic nerve to the brain names the colour of the object. Thus when sunlight falls on grass the rays whose vibrations produce the effect of red, yellow, blue, and violet are almost all absorbed, their energy being set to do work in the plant, and mainly those which produce the sensation of green are sent back to the eye. Similarly when light falls on a sliced beetroot the yellow, green, blue, and violet-producing vibrations are absorbed and mainly the red-producing rays sent back. When light falls on a piece of charcoal it is all absorbed, and as none is reflected the body appears devoid of light, or black. A sheet of paper, on the other hand, absorbs very little of the light and reflects white light as white. The fact that colour resides in the light, not in the object, may be illustrated by sprinkling salt on the wick of a burning spirit-lamp. The sodium of the salt gives out light of one wave-length only, producing the sensation of yellow. In this light objects which reflect all kinds of light and those which reflect yellow appear yellow, but such things as beetroot and grass absorb all the yellow light and appear black, like charcoal, which absorbs all light whatever, and the most brilliant painting appears in tones of black and yellow only.

Heat and Temperature.—The action on matter of radiant energy, particularly of the comparatively long and slowly vibrating waves known as heat, is to make the particles oscillate more rapidly. When the particles of matter vibrate rapidly they send out waves of radiant energy, and thus a heated body radiates heat. Two bodies are said to be at the same temperature when each communicates the same amount of heat to the other as it receives from it. If one body by conduction or radiation communicates to another body more heat than it receives from it, the former is said to be at a higher temperature. The hand plunged into water lets us know whether the water is at a higher or lower temperature than the hand. If the water is at a higher temperature, heat passes into the hand which feels warmth, if the water is at a lower temperature heat passes out of the hand which feels cold. The amount of heat which causes in a small body a great rise of temperature causes in a large body a much smaller rise of temperature. Heat is the total amount of molecular motion in the mass, while temperature depends on the rate of that motion. The unit of heat used in this volume is the amount required to raise the temperature of 1 lb. of water 1° F. Temperature is measured by the thermometer.

Capacity for Heat.—Heat bears to temperature exactly the same relation as volume of a liquid does to level. When a large quantity of liquid must be poured into a vessel to raise the level one inch, we say that the vessel has great capacity; while if only a few drops are required to raise the level one inch, the vessel is said to have small capacity. It is level alone that decides the direction in which the liquid will flow when two vessels are connected by a pipe. Similarly there are some kinds of matter one pound of which requires a great deal of heat to raise its temperature by one degree, while an equal mass of others is raised in temperature to the same amount by very little heat. The former class of substances are said to have a great *capacity for heat*, or, as it is sometimes called, a high *specific heat*. Thirty times as much heat is required to raise the temperature of 1 lb. of water 1° as to raise the temperature of the same mass of mercury by the same amount. On the same fire, if other conditions are the same, mercury becomes as hot in a minute as an equal mass of water does in half an hour; but then as a necessary consequence heated mercury cools as much in a minute as an equal and equally heated mass of water does in half an hour. Water has the next greatest capacity for heat to hydrogen, the capacity for heat of which is about 3½ times as great.

Expansion by Heat.—When the temperature of matter is raised the oscillations of the particles are not only more rapid but of greater amplitude. Each particle occupies a greater space in its longer swing, and consequently the volume occupied by the matter is increased and the density diminished. Expansion of volume by heat takes place in solids, liquids, and gases alike, though its amount is different in each kind of matter and is always greater for gases and liquids than for solids. The lengthening of a bar of iron when heated or its contraction when cooled takes place with nearly irresistible force. The rails of a railway 400 miles long, say between London and Edinburgh, are nearly 1000 feet longer on a summer afternoon than on a winter night. The expansion of a metal rod is often used as a measure of temperature; but thermometers (Appendix I.) are usually made by taking advantage of the greater expansion of liquids or gases. If heat is applied to the lower part of a vessel containing liquid the layer next the source of heat is raised in temperature, expands, and becoming less dense rises to the surface, allowing the denser liquid above to subside to the bottom and get heated in its turn, thus setting up complete circulation throughout the mass. This transmission of heat by the translation of heated portions is called *convection*, and in consequence of it the temperature of a liquid heated from beneath becomes much more rapidly uniform than that of a solid. The conduction of heat in liquids is very slow, and when the upper layer is heated the vibrations of its particles are passed on by conduction to the mass below very slowly indeed, as the expanded upper layer tends to remain in its position.

States of Matter.—If the particles of any kind of matter were absolutely at rest, that is to say if they possessed no kinetic energy, it is assumed that the body would be at the absolute zero of temperature. This total absence of heat has not yet been observed, though it has very nearly been reached. The difference between the same substance in the solid, liquid, and gaseous states is due to the rate of motion of the particles alone, and the work of moving the particles may be readily expressed in terms of heat. Thus in solids which contain relatively little heat the particles move so slowly that cohesion confines them to excessively minute paths, and the substance possesses rigidity. In the liquid state there is much more internal movement or heat, and the particles having a longer path and greater rapidity of motion partly overcome cohesion and show the property of fluidity. Gases contain so much heat that the particles are set in very rapid motion through comparatively long paths and cohesion is quite overcome. When the pressure remains the same, every additional degree of temperature makes the particles of a gas move more quickly through a longer path, and the volume occupied by the gas is increased by $\frac{1}{490}$ of its volume at 32° ($\frac{1}{273}$ for 1° C.). A fall of 1° reduces the volume by $\frac{1}{490}$. Hence a fall of 490° of temperature in a gas at 32° should reduce its volume to nothing, which is impossible; hence it is believed that no gas or liquid can exist at -458° F. In other words, only solids could exist, and their particles would be motionless, that is, absolutely without heat or at the *Absolute Zero* of temperature.

Action of Heat on Ice.—We may follow the action of heat on matter by supposing radiant heat to be supplied to a mass of 1 lb. of ice at 0° F. Each unit of heat raises the temperature of the mass by 2° (hence the capacity for heat of ice is only half that of water), and by the time 16 units of heat have been absorbed, the mass of ice has expanded considerably, and its particles are vibrating with increased energy so that the temperature is 32°. The next 144 units of heat which enter the mass produce no effect on the temperature, which remains at 32°. But the energy is doing other work, for when the 144 units have been absorbed we are dealing with water, not ice. Those 144 units have been expended in work against cohesion and are stored up as potential energy. The heat employed in doing this work of separating particles is sometimes said to become latent, and the *latent heat* of water, *i.e.* the amount of heat necessary to change 1 lb. of the solid into 1 lb. of the liquid substance, is 144 F. heat-units.

Action of Heat on Water.—The volume of 1 lb. of water at 32° is 8 per cent. less than the volume of 1 lb. of ice. This is a very significant fact, for almost all other substances occupy a greater volume in the liquid than in the solid state. When 7 heat-units are absorbed by 1 lb. of water at 32° the temperature rises to 39°, but the volume continues to diminish, a state of things which appears to show that in water, unlike almost all other liquids, the faster moving particles fit in a smaller space. But after 39° is past each fresh unit of heat raises the temperature by about 1°, and the volume of the liquid increases faster and faster. From 32° the addition of 180 heat-units raises the temperature to 212° at ordinary atmospheric pressure; but here another change takes place, and the water is said to boil. No less than 967 units of heat must be supplied before the temperature of 1 lb. of water rises above 212°, and at the end of that operation there is not water but 1 lb. of steam or water-vapour, at 212° A real experiment would not proceed so regularly as is here assumed, because at all temperatures water, and even ice, are partly converted into vapour, and in this change a certain amount of heat is used up.

Action of Heat on Water-vapour.—The work done by 967 heat-units on 1 lb. of water at 212° was done once more against cohesion. The vibrating particles have been enabled to increase the amplitude of their oscillations to a great extent, the volume of the gaseous steam being 1700 times as great as that of the water from which it was derived, and the particles of vapour are darting with the average speed of nearly 1 mile per second. When heat is supplied to steam every unit raises the temperature by 2° (its specific heat being only half that of water); the rise of temperature means increase in the velocity of the darting particles and brings about an increase of volume by $\frac{1}{490}$ part for each degree if the pressure upon the vapour remains the same, or a corresponding increase of pressure on the sides of the containing vessel if expansion is prevented. When water-vapour is raised to a very high temperature the heat begins to do the work of breaking up the molecules of water into its components oxygen and hydrogen, thus doing work against chemical attraction and storing up potential energy in the separated gases.

Pressure and Change of State.—Under pressure ice melts at a lower temperature than 32°, and the few other bodies which contract when they liquefy also have their melting-points lowered by pressure. Bodies which expand when they liquefy—like mercury, rocks, and most other substances—have their melting temperatures raised by pressure so that more heat is required to liquefy them. The effect of pressure on the temperature at which the change from liquid to gas takes place is much more marked. In every case an increase of pressure delays complete vaporisation or boiling until a higher temperature is reached. Water, for example, can only be heated without boiling to a temperature of 68° if the atmospheric pressure is one-fortieth of its average amount, but to 176° at half the usual pressure, and to 250° if the usual pressure is doubled. The boiling-point of a liquid may thus be used to measure atmospheric pressure.

Heat-energy.—The changes which take place when heat is withdrawn from matter are the exact opposite of those accompanying the application of heat. When oxygen and hydrogen unite, the potential energy of separation is changed into kinetic heat-energy, as already explained. When 1 lb. of hot water-vapour radiates out its heat-energy its temperature falls gradually to 212° at ordinary pressure; but then, in assuming the liquid state, 967 heat-units are given out as the particles come together under the influence of cohesion. One pound of steam at 212° if passed into 4 lbs. of water at 32° gives out heat enough in liquefying to warm up the whole 5 lbs. of water to 212°; hence the great value of condensing steam as a heating agent. One pound of water cooling from 212° to 32° gives out 180 heat-units, and as the particles come fully under the influence of cohesion and group themselves into solid crystals of ice, the energy that held them apart is changed into 144 units of heat.

Mechanical Equivalent of Heat.—The great task of measuring the quantity of heat-energy which is equal to a certain amount of work (p. 17), and so of comparing the invisible motion of molecules with the visible motion of masses, was attempted and triumphantly accomplished by Joule in 1843, when the modern theory of energy was founded. One heat-unit is equal to 777 foot-pounds. In other words, if a mass of 1 lb. were to be pulled down by gravity through 777 feet, and the whole of its kinetic energy changed into heat in 1 lb. of water at 32°, the temperature of the water would be thereby raised to 33°. Thus we can measure the work done by heat in melting 1 lb. of ice at 32° and find it to be equal to 112,000 foot-pounds, while that done in evaporating 1 lb. of water at 212° is 751,000 foot-pounds. It appears that the heating of 1½ lbs. of ice at 32° until it becomes steam at 212° requires as much energy as the feat of mountain-climbing described on p. 32.

Degradation of Energy.—It is always possible and easy to change work, electric power or light into heat, and 777 foot-pounds of work will always yield the full heat-unit. The inverse operation is different, and from 1 unit of heat the best machine it is possible to imagine could only obtain a small fraction of its equivalent of work. As water tends to flow to the lowest level, so in Nature energy of every kind tends to assume the least available form, which is that of heat. This process is called the degradation of energy, and in course of time, if it continues to act, all the energy of the

Universe will be reduced to the form of heat-vibrations in one uniform mass of matter at one uniform temperature, and although present in full amount quite unavailable for doing work. The atoms of all radioactive elements liberate energy while undergoing spontaneous transformation, and this fact deprives of value the arguments as to the age of the Earth and of the solar system, which used to be based on the rate of cooling of bodies at a high temperature.

Electrical Energy is not yet sufficiently understood to admit of its nature being simply explained. It may be viewed as a collective name for electrons which are considered to be constituents of the chemical atoms and are of two kinds, positive and negative (p. 31). This theory places electricity in a remarkable position, uniting the constitution of matter and energy, the electron being viewed as ether in a state of strain. Electricity is often spoken of as a fluid, but this is simply the survival of a more dense ignorance as to its nature. Electrical energy appears to take part in nearly every change of matter as to composition or state. It has the power of decomposing many chemical compounds which resist the action of every other form of energy, and it can also make some elements combine together which do not unite by any other means. As heat is transmitted from matter at a high temperature to matter at a low temperature, so electricity passes from matter at a high electrical potential to matter at a lower potential. This passage of electricity is called an electric current if it occurs quietly, or an electric discharge if accompanied by a flash or report.

Conductors and non-Conductors.—Electricity passes readily through some substances, such as copper, silver, metals of every kind, sea-water, damp earth, etc., and these are called conductors. Other substances, such as dry air, glass, sealing-wax, allow it to pass with such difficulty that they are called non-conductors. There is no perfect conductor, nor any absolute non-conductor. Even copper and silver offer a certain resistance to the passage of electricity, and *if the difference of potential is sufficiently great, electricity will overcome the greatest resistance of glass or air. The energy expended by electricity in overcoming resistance is changed directly into heat or light vibrations, as in the case of an electric lamp.*

Disruptive Discharge.—When the amount of electricity on the surface of a small body increases, the potential rapidly rises, and a transference of electricity takes place along the path that offers least resistance. With high potential, electricity can force its way across an interval of air, and as the resistance of air is very great much of the electrical energy is transformed into heat in the process, and the particles of air are set in such violent vibration that they become luminous. Such a transference is called a disruptive discharge, or when it occurs in Nature a flash of lightning.

Magnetism.—An oxide of iron which exists naturally in considerable quantities has the power of attracting to itself pieces of iron, this attractive force being much more powerful than gravitation. When a bar of this mineral is cut, and so uniformly shaped that no difference in appearance can be found between its two ends, the ends still differ, much as the right hand differs from the left. If the bar be balanced on a pivot it will turn and come to rest with one end pointing toward the north. On this account the mineral is called the *lodestone.* If two similar bars are balanced in this way the north-seeking end of each can be found and marked. The effect of one such lodestone on another emphasises the difference between the two ends. If the north-seeking end of one lodestone is brought near the south-seeking end of another which is balanced the latter is strongly attracted, but if brought near the north-seeking end of the balanced lodestone there is as strong repulsion. The property of two-endedness in bodies outwardly similar is called polarity, and the ends are termed poles. The rule of magnetic attraction and repulsion is very simple—*Unlike poles attract, like poles repel.* The lodestone imparts all its properties to steel when rubbed upon a bar of that metal, and such steel bars are then termed magnets.

Electro-magnetism.—The properties of magnets would be inexplicable had not an accidental discovery shown the close relation of magnetism and electricity. It was found that when electric energy is passing through a wire placed above a balanced magnetic needle, the needle swings round and tends to set itself at right angles to the wire. It was found later that when a coil of copper wire traversed by electricity surrounds a bar of iron, the iron becomes a powerful magnet and retains its properties of polarity and attraction as long as the electricity passes, losing them the instant the current ceases. A coil of copper wire without any iron in the centre was subsequently found to possess polarity, and to exert attraction and repulsion as long as an electric current flowed through it. Hence magnetism can be produced by electricity, and the reverse also holds good. A magnet thrust inside a coil of copper wire generates a momentary current of electricity. By merely making a coil of wire move in the field of a powerful magnet electricity can be produced in the wire, and thus work can be changed directly into electric current; the vast modern development of electricity for lighting and power depends upon this fact.

In Nature nothing is so simple as has been represented in this and the last chapter. We do not know how particles vibrate and oscillate, and only guess at the real nature of the forms of matter and energy. Authorities differ in their interpretation of many of the facts, and we have only presented a few of the simpler conclusions in order to assist the student who does not know much of physics and chemistry to follow the chapters which come after.

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CHAPTER IV

THE EARTH A SPINNING BALL

The Earth a Sphere.—The field of view at sea or on a level plain is always bounded by an unbroken circle called the horizon ; and in all parts of the Earth when one watches a receding object at sea or on a level plain the horizon appears slowly to swallow it up, and it disappears like a traveller over a hill. In all parts of the Earth if the eye is placed 5 feet above sea-level the lower 5 feet of any object are concealed when 4½ miles away. Across a lake 5 miles wide, two men of ordinary height standing erect and looking at each other with telescopes can see only the head and hands of the other apparently floating on the water, their bodies being entirely concealed from view (Fig. 9). So from the sea-shore the hull of a ship 10 feet above the water vanishes at 6 miles' distance, and its masthead 100 feet high sinks out of sight at 15 miles. Since the same length of an object is concealed by the horizon at the same distance from the observer in all parts of the Earth, it is evident that the dip of the horizon, as it is termed, is practically the same everywhere, and that the surface of the Earth is uniformly curved in a convex form. The only figure which has uniform convex curvature is a sphere, and the Earth is hence generally spoken of as being a sphere or globe. From 8 feet

FIG. 9.—Curvature of the Earth, exaggerated 400 times.

above sea-level the horizon is only 3 miles distant; from a height of 5,600 feet it is 80 miles, so that an observer can see to a distance of 80 miles all round; while from 24,000 feet it is more than 160 miles distant, and in each case a perfect circle.

The Earth an Ellipsoid.—If the Earth were a perfect sphere its size could be measured by measuring the length, in miles or yards, of the arc of a great circle (*i.e.* a circle the centre of which is at the centre of the Earth) subtending one degree, and multiplying by 360 to give the circumference, for each degree subtends an equal arc on a sphere. It is easy by observations of the stars to tell exactly how many degrees one has advanced along a great circle; and parts of great circles (arcs of the meridian) have been measured in many parts of the Earth with much exactness. In Great Britain 1° was found to be almost exactly 365,000 feet long; but in Peru 1° was found not quite 363,000 feet in length, and in the north of Sweden 1° was found to measure about 366,000 feet. These measurements are probably correct to within a few feet; and the only conclusion that can be drawn from them is that the Earth is not a sphere, but a figure the curvature of which is less than that of a sphere in some parts and greater in other parts. It resembles a sphere slightly compressed along one diameter, and correspondingly bulged out in the direction at right angles. The length of the shortest diameter has been calculated as 7899·6 miles (about 500,000,000 inches), and the diameter at right angles as 7926·6 miles. The circumference is about 24,000 miles. The form is very nearly that known as an ellipsoid, or oblate spheroid of revolution—a figure that could be made in a turning-lathe, with the axis of rotation in the lathe as the shortest diameter.

The Earth a Ball.—The most exact measurements which have been made, show that the figure of the Earth is not a true ellipsoid. It appears to be compressed to a slight extent at right angles to the shortest diameter, so that the equatorial diameters vary in length by one or two miles. The exact form of the Earth is being gradually discovered by very careful measurements of the force of gravity carried out by means of a pendulum or a fine spring-balance. The weight of a given mass on the Earth's surface depends only on its distance from the centre, and thus as the strength of gravity at different places is found, the figure of the Earth is gradually felt out. The form of the Earth is termed by mathematicians a *geoid* or earth-like figure; and it is more accurate to speak of it as a ball than as an ellipsoid or sphere. Yet the difference in shape is so slight that if a geoid or ball, exactly like the Earth, an ellipsoid and a sphere were made each a foot in one diameter, it would be quite impossible to tell which was which by the eye or touch.

Structure of the Earth.—The Earth is a structure composed externally of three divisions—(1) a vast stony ball termed the *lithosphere* with an irregular surface, part of which forms the dry land; (2) a liquid layer resting in the hollows of the lithosphere, a great part of which it covers; this is termed the *hydrosphere* or water-shell; and (3) a complete envelope of gas surrounding the whole to a considerable height and known as the *atmosphere* or air.

Mass and Density of the Earth.—To weigh the Earth, all that is necessary is to measure the attraction of gravity between a large block of metal and a small block set at a measured distance. Then (making allowance for the distance of the small block from the Earth's centre) the attraction of the large block on the small one bears to the weight of the small one, *i.e.* the attraction of the Earth on it, the same proportion as the mass of the large block bears to the mass of the Earth. Cavendish, who first carried out this experiment in 1798, employed a cumbrous apparatus in which the large attracting mass took the shape of two leaden balls a foot in diameter. The small block consisted of two small leaden balls fixed to the ends of a light rigid rod, which was hung by a fine silver wire. This arrangement is termed a torsion balance, because when the small spheres were attracted by the large ones and moved slightly towards them the wire was slightly twisted, and the force required to twist the wire to that extent having been found by experiment, was a measure of the attraction between the small and large spheres. The weight of the small balls is the measure of the attraction of the Earth upon them, and as the distance of the small balls from the centre of the Earth is known, the mass of the Earth can be calculated from the known mass of the large leaden spheres. The experiment has been repeated in an improved form by many investigators, and finally Mr. Vernon Boys devised a method by using a very fine elastic thread of quartz which acts as an extremely sensitive spring, and succeeded in measuring the force of attraction between bodies as small as ordinary bullets. As the result of several independent methods, the mass of the Earth has been found to be the same as if it were a globe of homogeneous substance 5½ times as dense as water; the mean density of the Earth is thus said to be 5·5.

The Earth in Motion.—On a clear morning the bright disc of the Sun appears somewhere on the eastern horizon, it rises slowly and, as the day advances, wheels round the sky, then, as slowly sinking, it disappears somewhere on the western horizon. When the Sun is visible its light fills the whole sky, which appears as a bright blue dome if cloudless. Sometimes a glimpse may be had of the Moon, as a ghostly white broken disc like a little fleecy cloud; very rarely, indeed, the bright light of a planet is visible, or the weird form of a comet. At night the curtain of the Sun's excessive light is removed, and we see that the whole sky is really gemmed over with bright points or stars, as if a dome or hollow sphere of black paper pricked with innumerable holes had been wheeled between us and the Sun. This star-dome appears to revolve round the Earth, the various marks on it preserving an unaltered arrangement. The stars have been grouped into fanciful constellations, which are easily recognised and serve as a rough-and-ready way of naming any definite part of the sky. By a curious mixture of guessing and of reasoning on the observations which they made, Copernicus and Galileo and their followers came to the conclusion that the regular changes in the appearance of the sky from hour to hour and month to month could only be accounted for by the Earth having at least two different kinds of motion. The first convincing proof of the Earth's motion was the discovery that a weight dropped from the top of a high tower did not reach the Earth's surface perpendicularly under the point from which it was let go, but always a little to the east.

Rotation of the Earth.—The old difficulty that the Earth could not be moving because we do not feel it, or that the star-dome could not be fixed because we see it move, no longer troubles us because we are familiar with the imperceptible motion of a well-started train, and the apparent gliding away of the platform in the opposite direction. The Earth spins uniformly and regularly from west to east, as may be inferred from the uniform and regular apparent rotation of the starry sky at night. The first Law of Motion (p. 32) enables us to understand how the rotation of the Earth has been actually proved, and what the immediate consequences of rotation are. The French physicist Foucault showed how a large pendulum once set swinging changed the plane of its swing slowly and regularly. If started, for instance, swinging above a table from north to south, after a certain time (varying with the latitude) it would be found swinging from east to west, and in twice that time it would have changed its plane still further and be swinging from south to north again. Since the only force which could act on a moving pendulum hung from the solid roof of a building is the rotation of the Earth, this change in the direction of the pendulum proves it. The pendulum does not really change its direction of swinging in space; it remains in a state of uniform motion, and the apparent twisting is produced by the house and the whole Earth turning while the pendulum marks out its invariable line.

Polarity.—A ball at rest has no ends or natural points from which to reckon position, but as soon as the ball is made to spin two opposite points on its surface become different from all others, although there may be no visible mark or sign of the fact. These points, which are called ends or poles, are relatively at rest like the centre of a wheel, and the rate at which a point on the surface of a spinning ball moves is greater in proportion to its distance from them. A body spinning uniformly turns round the axis (NS in Fig. 12) or line joining its poles as a wheel spins round an axle. The two poles of a spinning body are distinguished from each other by the apparent direction of rotation about them. Looking down on the Earth from above one pole, an observer would see the surface rotating in a direction opposite to that of the hands of a watch, as shown by the thick arrow (Fig. 10), while if he were to look down similarly on the other pole the surface would appear to rotate in the same direction as the hands of a watch do (thick arrow, Fig. 11). The end first mentioned is called the North Pole, and the opposite is named the South Pole. The Earth always rotates in one direction, from west to east (arrows in Fig. 12); the apparent difference at the poles is due to our looking from opposite sides. The arrow of Fig. 10 appears turning to the left in its flight, that of Fig. 11 appears turning to the right, but on holding the page up to the light they are seen to be one and the same. The student should, if possible, make himself familiar with this by actual observations on a terrestrial globe.

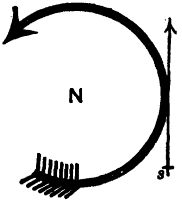

FIG. 10.—Direction of Rotation round North Pole, and Direction of Deviation of Moving Bodies in Southern Hemisphere.

Law of Deviation.—On a steamer at rest or moving steadily straight forward a passenger has no difficulty in walking in a straight line parallel to the planks of the deck, or in any other direction. But if the steamer is turning rapidly to the right, the promenader, trying to keep in a straight line, has the greatest difficulty in preventing himself from deviating to the left and running against the bulwarks; or if the steamer is turning to the left he can hardly help deviating to the right with reference to the planking. The passenger tends to continue walking in a straight line with regard to objects outside the ship all the while, and the real motion of the deck toward the right gives an apparent motion of the passenger toward the left. The same is true of everything moving on the surface of the rotating Earth, whether the moving body be a shot from a cannon, a railway train, a river, or simply wind. This fact was thus stated by Ferrel, whose name is often associated with the law: *If a body moves in any direction on the Earth's surface, there is a deflecting force arising from the Earth's rotation, which deflects it to the right in the northern hemisphere, but to the left in the southern hemisphere.* The moving body has a tendency to keep on in a straight line; it is the Earth that changes its direction, as in Foucault's pendulum experiment. Fig. 10 represents the apparent deviation of a body moving in the southern hemisphere, Fig. 11 that in the northern—the thin arrow showing the original direction, the thick arrow the deviation.

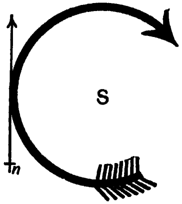

FIG. 11.—Direction of Rotation round South Pole, and Direction of Deviation of Moving Bodies in Northern Hemisphere.

Position of the Axis.—The axis of the Earth about which it rotates is the shortest diameter. If the Earth was once much hotter than now and in a semi-fluid condition (as there are good reasons to believe it was), the mere fact of its rotation would make it bulge out along the line farthest from the poles, and that to the precise degree which is found to exist. As in the case of the rapidly-spinning gyroscope (p. 33), and for the same reason, the axis of the Earth preserves its direction practically unchanged in space; and consequently the ends of the axis always point to opposite parts of the starry sky. As the Earth rotates, these points—the poles of the heavens—appear to be at rest, while the sky with its constellations appears to revolve round them from east to west. The north pole of the Earth points very nearly to a bright star which has received the name of the Pole Star or *Polaris*, and is of the greatest importance as a guide to direction and position on the Earth in the northern hemisphere.

Direction on the Earth.—On account of the Earth's rotation it is possible to fix direction and position on its surface. The line which we may imagine to be traced round the Earth equally distant from both poles is termed the *Equator*, and it is the only great circle the plane of which cuts the axis at right angles. The half of the globe in which the north pole is situated is termed the northern hemisphere; the half whose centre is the south pole is the southern hemisphere. Great circles running through the poles, and therefore having a north and south direction, are called *meridians*. The direction toward which the Earth turns is called the east, that from which it turns the west. East and west thus indicate merely a direction of turning, and do not refer to fixed points. Small circles traced round the Earth, their planes cutting the axis at right angles, have thus an east and west direction and are called *parallels*. They are, of course, smaller and smaller as the poles are approached. The equator, meridians, and parallels are clearly shown on the maps of the world in the various plates.

Latitude is the name given to the angular distance, at the centre of the Earth, of any point on the surface from the equator measured toward the poles. The equator is chosen as 0° of latitude, and as the distance of the poles is a quarter turn or right angle (p. 20) the north pole has latitude 90° N., the south pole latitude 90° S. The latitude of any place, except the poles, merely refers to the distance from the equator of a small circle, or parallel of latitude, passing through the place in question. Latitude is always measured astronomically by observing the altitude of the pole of the heavens, directly or indirectly. The altitude of the pole, or its angular distance above the horizon of an observer, is equal to the angular distance of the observer from the Earth's equator. Standing on the equator an observer (if the effects of refraction are not considered) would see the north pole of the heavens close to the pole star on the northern horizon, and the south pole of the heavens on the southern horizon, while all the stars would appear to rise in the eastern half of the sky, to describe vertical semicircles, and sink on the western side. If the observer were to journey farther north he would lose sight of the south pole of the heavens, while the north pole would rise higher and higher above the horizon. By the time he had got half-way from the equator to the pole (45° N., at O Fig. 12) the pole star would appear to have risen half-way from the northern horizon toward the zenith, an elevation of 45°. All the stars within 45° of the pole would remain in sight all night, never rising or setting, but circling round the pole; a star exactly 45° from the pole would describe a circle, passing through the zenith at its highest point, and touching the northern horizon at the lowest. Stars beyond that limit would rise in the eastern part of the sky, describe oblique arcs, and set in the western; while stars more than 135° from the north pole of the heavens would never become visible. Finally, at the north pole of the Earth, the pole of the heavens would appear in the zenith (altitude of 90°). All the stars within 90° of the pole would be visible, but no others. They would never rise nor set, but always wheel round in horizontal circles, once in twenty-four hours. Measuring with a sextant the altitude of the pole of the heavens above the horizon thus gives the latitude of the observer. In practice the altitude of some bright star or of the Sun when at the highest point of its daily apparent path is observed, and the relative position of the Sun or star being given with proper corrections in the *Nautical Almanac*, it is easy to calculate the latitude. Thus the exact position of an observer on the Earth with respect to the poles can always be found by observations of the Sun or stars without any measuring of distances on the surface. A degree of the meridian varies a little in length (p. 53) but averages 69·09 miles; the sixtieth part of this, or one minute of latitude, measures nearly 6000 feet, and is called a sea-mile, or nautical mile; the second of latitude measures about 100 feet.

Angular and Tangential Velocity of Rotation.—The Earth turns on its axis uniformly, and the rate of turning or angular velocity is the same at all parts. A line drawn perpendicularly from the equator to the Earth's axis at C describes a whole turn in the same time as a line drawn perpendicular to the Earth's axis at A from a point B in 60° latitude. But the line CE is nearly 4,000 miles long, while the line AB is not 2,000 miles; therefore during the time of one rotation the point E is carried through more than 24,000 miles, while the point B is carried through little over 12,000 miles, and the points N and S are at rest. The rate of movement of the Earth's surface by rotation is called its tangential velocity, and diminishes from over 1,000 miles an hour at the equator to 500 miles an hour at 60°, and 0 at the poles. A body resting on the Earth's surface has a tendency to fly away at a tangent on account of the rotation, like a stone in a sling, and the force of gravity is partly employed in preventing this. This centrifugal force (p. 33) makes bodies weigh less at the

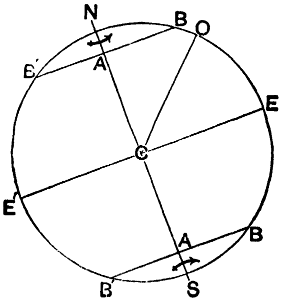

FIG. 12.—Diagrammatic Section of the Earth. C, Centre; CE, CO, CN, radii of the Earth; NS, axis; AB, perpendicular to axis; O, a point in 45° N. lat.; B, B, points in 60° lat.

equator than at the poles, reinforcing the very slight reduction of weight due to the fact that the equator is more distant than the poles from the Earth's centre (p. 24). If the Earth rotated seventeen times more rapidly than it does the centrifugal force would be equal to gravity, and if it rotated in the least faster the equatorial part of the Earth would split off like the edge of a burst grindstone. The increase of tangential velocity with length of radius enabled the fact of the Earth's rotation to be proved in the seventeenth century by dropping a weight from the Leaning Tower of Pisa, and observing the distance of its fall to the east of the perpendicular line. The weight was moving eastward with the top of the tower more rapidly than the base of the tower, and retained its original motion (while falling) in consequence of inertia.

Measurement of Rotation.—The period which elapses between the Sun crossing the meridian or north and south line of a place on two successive occasions is called a day, and is divided into 24 equal parts or hours; this is the apparent time occupied by the Earth in making one rotation. It is in many ways more convenient, and also more exact, to determine the period of rotation of the Earth by observing the successive transits of a conspicuous star. By this means the exact period of the Earth's rotation has been fixed as 23 hours, 56 minutes, 4 seconds. The name Sidereal Day is given to the rotation period of the Earth as measured by the stars, and astronomers divide it into 24 sidereal hours, subdivided into minutes and seconds of sidereal time.

Time.—The uniform rotation of the Earth is the only standard of time which is practically employed, and for common purposes the solar day of 24 hours is everywhere used as the unit. The Sun crosses the meridian of any place midway between its hour of rising and of setting, and the name meridian (mid-day) was given to the north and south line on this account. Mid-day or noon can be determined exactly by measuring the altitude of the Sun by a sextant or transit circle, or roughly by watching the shadow cast by a stick or a pillar. As the Sun is rising the shadow gradually becomes shorter, and at noon the Sun being at its highest the shadow is at its shortest, and marks out on the ground the north and south line or meridian of the place. The movement of mechanism actuated by a falling weight or an uncoiling spring, and regulated by a pendulum or a balance-wheel, is universally employed for time-measuring; but all clocks, watches, and chronometers must be adjusted according to astronomical determinations of the length of the mean solar day.

Local Time.—As the Earth turns, the Sun appears successively on every meridian. It is always noon somewhere, but it can never be noon on two meridians at the same moment. The rate of angular rotation is 360° in 24 hours, or 15° in 1 hour, or 1° in 4 minutes. Thus when the Sun is on the meridian of Greenwich it is 12 hours since it shone on the meridian of the Fiji Islands (180°), where it is consequently midnight. Two towns 15° apart differ by 1 hour in their local noon, so that it is necessary in describing the time of any occurrence to specify by what meridian the time is regulated. (See Plate I.) Greenwich time is used throughout most of the countries of Western Europe, and is officially termed Western European Time. In Scandinavia, Germany, the Eastern States, Switzerland, and Italy the standard time is one hour later. *i.e.* 1 P.M. at Greenwich noon, and is termed Central European Time, while in Russia, Eastern European Time, differing from that of Greenwich by two hours, should be used. Throughout the United States and Canada the time is changed by 1 hour at every 15° of longitude; so that in each belt the same time is shown on all the clocks, and between the Atlantic and Pacific there are five changes of this kind. The standard time in South Africa, Australia, India, and Japan is fixed similarly with regard to Greenwich. Travelling eastward or toward the sunrising has the effect of making the Sun rise earlier each day and set earlier each night; passengers on one of the fast eastward-bound steamers in the North Atlantic have their meals nearly an hour earlier each day than on the previous day and their watches appear to go slow. Going right round the world in an easterly direction the time cut off each day by meeting the Sun before the complete rotation of the Earth amounts to one whole day extra, so that, for example, in 100 Earth rotations the traveller has seen 101 noons, and recorded the doings of 101 days (each 1 per cent. shorter than a day at home) in his diary. Similarly going in a westerly direction the rising and setting of the Sun are delayed by an equal interval of time, and on going round the world westerly in 100 Earth rotations there have been only 99 noons and the doings of only 99 days recorded, each "day" of course being 1 per cent. longer than a day at home. Dates are kept right by repeating a day going eastward or dropping a day going westward on meridian 180°.

Summer Time is a device for securing an hour of additional daylight on summer evenings by keeping the clock one hour fast, in other words by using the time of a meridian 15° east of that of the locality.

Longitude.—The longitude of a place is the angular distance of its meridian from some prime meridian, that of Greenwich being usually adopted. In order to find the longitude of a place from the meridian of Greenwich it is only necessary to know the local time and Greenwich time at the same moment. Local noon is ascertained by direct observation of the Sun, or by observing the altitude of the Sun or some bright star at a distance from the meridian and calculating the hour angle. To get Greenwich time in remote places is more difficult. Accurate chronometers, very carefully regulated and rated, are always relied on, the average time shown by two or three instruments being taken as correct. If at noon local time, when the Sun is on the meridian, the chronometer shows that it is 11 A.M. Greenwich time, it is evident that an hour must elapse before the Earth has turned sufficiently far toward the east to bring the meridian of Greenwich under the Sun. The interval between the local meridian and that of Greenwich is therefore 1 hour's turning or 15°; and since the Earth is turning toward the east the local meridian must lie 15° E. of that of Greenwich. If at local noon in another place the chronometer showed 2 P.M. Greenwich time, it is evident that the Earth has been turning for 2 hours toward the east since Greenwich was under the meridional sun, and the place of observation lies 2 hours of turning or 30° W. The apparent position of the Moon on the star-dome at successive intervals of Greenwich time is given in the *Nautical Almanac*, the Moon thus serving as a clock-hand pointing to the hour. But seen from different parts of the surface of the Earth the Moon is displaced to one side or another, and it is necessary to calculate the angular distance of the Moon from certain stars as it would appear if measured from the centre of the Earth, just as correct time is only shown by a clock when the observer stands in front of it (p. 21). When this *correction for parallax*, as it is termed, is made, the lunar distances give the Greenwich time by a troublesome calculation and the longitude can thus be found. Since the great circle of the equator, the circle of only half the size of the parallel of 60°, and the minute circle immediately surrounding the pole are all divided into 360° of longitude, it is evident that while the arc subtending 1° on the equator is equal to that of a degree of latitude, a little over 69 miles, the arc subtending 1° of longitude at the parallel of 60° is only 34½ miles, and that close to the pole only a few feet or inches. The parallels of latitude are equidistant from each other, but the meridians of longitude converge and all meet at the poles.

Terrestrial Magnetism.—The rotation of the Earth is probably the cause which confers on the globe as a whole the properties of a great magnet (p. 50). The poles of the Earth-magnet are near the poles of rotation, but do not coincide with them; the north magnetic pole lies in 70° 51′ N., 96° 46′ W. and the south in 72° 25′ S., 155° 16′ E. (see Plate I.). When a small straight magnet is hung by a fine thread so that it can move freely in all directions, it takes up a position which in most parts of the world is nearly north and south, hence its use in the mariner's compass as a ready means of finding directions. A suspended magnet when free from any disturbing attraction points due north and south in all places marked in the map by the curves of 0° or agonic lines. The angle between the meridian and the direction of a suspended magnetic needle is called the *declination*, or by sailors the *variation* of the needle. Between the agonic lines over almost all Europe, Africa, the Atlantic and Indian Oceans, the needle points west of north, the lines in the magnetic chart showing the number of degrees in different places. In the north-west of Greenland the declination is 90°, or the needle points due west; while northward of the magnetic pole it is 180°, or the north-seeking pole turns due south. Over most of Asia, N. and S. America, and the Pacific Ocean, the declination is to the east of north. After a freely suspended steel needle, balanced so as to rest horizontally upon its pivot, is magnetised one end is found to be drawn downward by the magnetic attraction of the Earth. This phenomenon is called the *Dip* of the needle. Along a certain line on the Earth's surface there is no dip; this line is termed the magnetic equator and is shown in the map. North of it the north-seeking pole dips more and more until at the north magnetic pole it points vertically downward. South of the magnetic equator the south-seeking end of a suspended magnetic needle dips downward. The intensity of magnetic force varies from place to place, being nearly proportional to the dip. In certain regions the rocks beneath the surface of the Earth exercise a powerful attraction on a suspended magnet.

Periodical Magnetic Changes.—In 1576, when the declination of the magnetic needle was first measured in London, the north-seeking pole pointed 11° east of north, but the easterly declination gradually diminished until in 1657 the needle pointed due north, and, the change still continuing, in 1815 it pointed 24½° west of north. Since 1818 the declination has gradually diminished, being about 16° W. at London in 1912, and decreasing about 4′ per annum. The dip is subject to a similar slow change. These changes were formerly accounted for by supposing that the magnetic poles changed their position on the Earth's surface. Recent observations indicate that this is not the case; they rather suggest that the alteration of declination and dip may be produced by geological changes taking place in the Earth's crust. Captain Creak, as the result of the "Challenger" observations, states that the change is most rapid at several points in a line drawn from the North Cape along the Atlantic to Cape Horn, and that the British Islands are situated in the region where the rate of change is greatest of all. Regular changes of shorter period also occur, the needle daily swinging perhaps 5′ or 6′ to E. or W. of its average position and back again; and there is a yearly periodicity as well. Irregular variations of much greater extent, sometimes amounting to one or two degrees, are called magnetic storms, and are closely connected with the appearance of the aurora (p. 126). Auroras and magnetic storms are most frequent at intervals of about 11 years, corresponding to the periods of greatest frequency of sun-spots. It is remarkable that whenever a great uprush of heated gas takes place in the Sun, producing solar prominences (p. 80), there is a simultaneous disturbance of all the delicately-hung magnetic needles on the Earth. Thus it appears that while the Earth's magnetism resides in the massive rocks of its crust, and is probably produced and maintained by the Earth's rotation, the Sun's energy exercises a regulating or disturbing influence upon it.

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CHAPTER V

THE EARTH A PLANET

The Moon.—So far we have looked on the heavenly bodies as convenient marks blazoned on the hollow dome of space around the spinning Earth. On p. 65 it was implied, however, that the Moon at least was free to change its position on the star-dome. The Moon appears to move amongst the stars, from west to east, so fast that if we observe it rising due east at the same moment as a star, it will be seven times its own diameter behind the star on crossing the meridian, and the star will have set about half an hour before the Moon reaches the western horizon. The Moon often passes between us and a star, and occasionally it passes in front of the Sun, causing an eclipse. These facts prove that the Moon revolves round the Earth from west to east, and that it is the nearest of all the heavenly bodies. The diameter of the Earth affords a sufficiently long base-line for measuring the distance of the Moon accurately, the vertical angle at the Moon of the triangle of which the radius (or semi-diameter) of the Earth is the base, being 57′. This angle is called the horizontal parallax of the Moon, and shows that the diameter of the Earth as seen from the Moon would be 1° 54′. The parallax varies somewhat during a month, showing that the distance of the Moon is not always the same; but from its average value the average distance of the Moon is found to be 238,793 miles, or in round numbers 240,000. The apparent, or angular, diameter of the Full Moon as seen from the

Earth is about 30′; that is to say, 180 full moons, one above another, would extend from the horizon to the zenith. The diameter of a body subtending this angle at a distance of 240,000 miles must be about 2000 miles, or, to be exact, 2153 miles. The mass of the Moon has been estimated to be $\frac{1}{80}$ of that of the Earth; its mean density is thus about 3 times that of water.

The Moon's Surface.—The Full Moon appears to be diversified with patches of unequal brightness, but observations with powerful telescopes prove that it is simply a lithosphere surrounded by neither water nor air. Ring-shaped mountains closely resembling volcanic craters may be easily seen by using an ordinary field-glass, especially when the Moon is so placed that sunlight illuminates only part of the surface. The Moon shines by reflecting sunlight, and even when most brilliant its light is so feeble that if the whole visible sky (apparently equal to 105,000 moons) were to shine as brightly the effect on the Earth would only be equal to one-fifth that of the Sun. As the Moon revolves round the Earth we see the side turned toward us wholly lit by the Sun once a month and call it Full Moon. Each day the illuminated area grows less until in a fortnight the Sun is shining only on the side turned from us and we see the Moon dark, calling it New Moon. Illumination begins again as a slender crescent and in a fortnight it has increased to the full round.

Period of the Moon.—The Moon revolves round the Earth in 27 days, 7 hours, 43 minutes; but the interval of time between successive new moons or full moons (the lunar month) is rather more than two days longer. The Moon always presents the same aspect to the Earth—only one half, and always the same half, is to be seen, although now and again slight irregularities in its motion reveal a narrow additional strip at one edge or another. The fact that no one has seen the other half proves that the Moon rotates on its axis in exactly the same time as it revolves round the Earth. If it had no rotation we should see all round it. To prove this, pass a loop of thread over a drawing-pin fixed in a horizontal board or table and the other end of the loop round a pencil. Keep the cord stretched, and, holding the pencil between the finger and thumb *facing in the direction of the arrows* (*Fig.* 13), trace a circle without allowing the hand to rotate. The diagram shows that the drawing-pin, A, if endowed with vision, would see all sides of the pencil (represented by the arrows) in succession. Next trace a similar circle, holding the pencil firmly but keeping one side of it, say that covered by the thumb, toward the centre, so that the drawing-pin can only see the thumb-nail (arrow-head in Fig. 14). When the circle is complete the cramped position of the hand will prove that there has been rotation at the wrist. The fact of rotation is shown in the diagram by the arrow pointing successively in every direction.

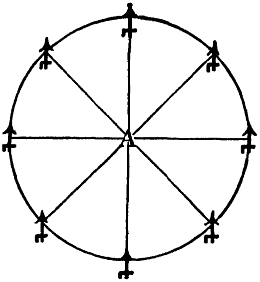

FIG. 13.—Revolution of a Non-rotating Body; presenting all sides consecutively to the Centre.

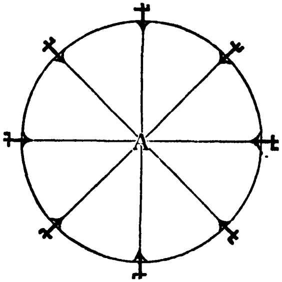

FIG. 14.—Revolution of a Body rotating once in the same time as it revolves; presenting always the same side to the Centre.

Differential Attraction and Tides.—Since attraction varies inversely as the square of the distance between the attracting bodies (p. 23), it follows that the Moon must exert a greater attractive power on the side of the Earth which is nearest to it than on that which is 8000 miles farther away. In consequence of this, the Earth is subjected to a stress tending to lengthen it out toward the Moon. The rigid lithosphere is not perceptibly strained; the gaseous atmosphere is so readily disturbed by other causes acting irregularly that only the slightest effect from this cause can be detected in it; but the liquid hydrosphere responds readily and swells into a long low wave, the crests of which are on the opposite sides of the Earth, and equal troughs between them. As the Earth rotates, high water and low water succeed each other regularly, from east to west, as the crest and trough of the wave pass at intervals of about 6½ hours. Without mathematical reasoning it is impossible to explain how the tidal wave, pulsating round the world, is related to the actual position of the Moon in its orbit and in the sky. On account of the formation of tidal currents, the hydrosphere may be supposed to be gently pressed like a brake on the lithosphere by the differential attraction of the Moon; and as the energy of the currents comes from the Earth's rotation, the rate of rotation at the end of each century is slower by the fraction of a second, and the time of rotation, or day, is longer in the same minute proportion.

The Tidal Romance of the Moon.—Millions of years ago the Earth must have rotated much more rapidly than now, when it suffers from long application of the brake. At that remote epoch the Moon was probably much nearer than now, for it is a property of revolving bodies, which cannot be explained here, that any reduction in the rate of the Earth's rotation is necessarily accompanied by an increase in the Moon's distance. The nearer Moon must have raised far greater tides than those we now know, in the more extensive and denser hydrosphere of those ancient days. In the remotest past on which this argument casts light the Moon must have been close to the Earth, whirling round its little orbit in the same time as the Earth spun round on its axis, which was then only a few hours. The Moon, indeed, seems to have been originally part of the semi-fluid Earth whirled off by the furious rotation of the earliest times. As the Moon receded from the Earth in its slowly widening spiral path it also had a hydrosphere in which the Earth's differential attraction raised tides, the friction of which gradually brought the rapid rotation of our satellite to correspond with its period of revolution round the Earth.

The Sun even more conspicuously than the Moon, separates itself from the other heavenly bodies, which are dim by contrast with its brilliance, and when the Sun rises vanish from sight like tapers when an electric arc is turned on. The altitude of the Sun at noon, observed at any place, varies throughout the year, increasing day by day until a certain maximum is reached, and then decreasing gradually to a minimum. The period from highest Sun to highest Sun, as observed in regions outside the tropics, is about 365 days. The angular diameter of the Sun when measured daily is found to increase gradually from a minimum of 31′ 32″ to a maximum of 32′ 36″, and then to diminish again to its former value, and this change also takes place in about 365 days. Unless with the aid of a very powerful telescope we cannot see the stars in daylight so as to be able to tell amongst what constellations the Sun appears at noon; but we know that these stars are just opposite those which cross the meridian at midnight. In the course of 365 days all the constellations of the star-dome successively cross the meridian at midnight, and from this fact we know that the Sun, like the Moon, appears to move amongst the stars from west to east, although in a year instead of a month.

Problem of the Earth and Sun.—The most natural explanation of the Sun's annual path amongst the stars is that the Sun, like the Moon, revolves round the Earth, but in a year instead of in a month. Another hypothesis, that the Earth revolves round the Sun, would also explain the facts. In Fig. 15 both hypotheses are illustrated. S represents the Sun, E the Earth, the arrow ESN shows where the Sun appears amongst the stars at noon, and the arrow EM shows what stars cross the meridian at midnight. The dark circle is the hypothetical orbit of the Earth round the Sun, the lighter circle the hypothetical orbit of the Sun round the Earth. The arena is so vast that the gyrating globes are both practically at the same distance from the amphitheatre of stars. Whether we assume that the arrow ESN, passing through the Sun, turns round the centre E, or that the arrow ESN, passing through the Earth, turns round the centre S, the arrow would point successively to the same parts of the star-dome, and observation of the stars would not decide which is the correct hypothesis. The law of gravitation explains that two revolving bodies circle round the centre of gravity of the pair. In the case of the Earth and Moon the centre of gravity of the system lies within the Earth, hence the Moon appears to revolve round it. It remains to inquire where the centre of gravity of the Earth and Sun lies; in other words, whether, and by how much, the Earth or the Sun is the greater body.

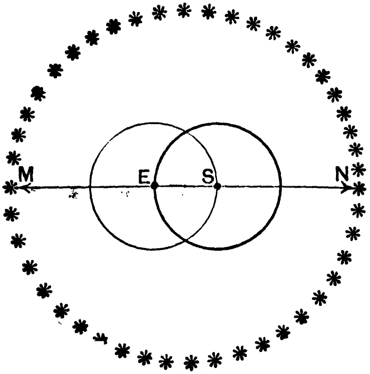

FIG. 15.—Problem of the Earth and Sun, showing how observation of the Sun's place amongst the Stars cannot tell whether the Earth (E) goes round the Sun (S), or the Sun goes round the Earth.

The Sun's Distance and Mass.—The horizontal parallax (p. 68) of the Sun is not quite 9″; and being so minute it is not easily measured accurately. Since the Sun's parallax is about $\frac{1}{380}$ of the Moon's, it follows that the Sun must be about 380 times more distant from the Earth than is the Moon. Accurate determinations give the average distance as 92,800,000 miles. Since the Sun subtends as large an angle to our eye (about 32′) as the Moon does, it follows that the Sun, being 380 times as distant, must have a diameter 380 times as great as that of the Moon, that is to say, about 800,000 miles. The Sun's volume is thus more than 1,200,000 times that of the Earth. By the attractive force it exerts the Sun's mass is proved to be more than 300,000 times that of the Earth. The centre of gravity of the Earth-Sun System must, indeed, lie within the Sun, and it is therefore as certain that the Earth goes round the Sun as that a weight of 50 lbs. will cause 1 grain to fly up if the two are placed in the opposite scales of a balance.

Proof of Revolution.—If a man, sitting in a motor-car on a dead-calm day while a steady downpour of rain is falling, finds the raindrops driving against his face instead of falling straight upon his cap, he concludes correctly that this *aberration* or wandering of the raindrops from their normal path is due to the fact that the car is not at rest but in rapid motion. By estimating the angle at which the rain strikes he may even calculate the rate at which he is being carried along. The astronomer, sitting in his observatory, detects a similar aberration in the light-rays from each of the stars. He finds the light reach him at a different angle at various times of the year, so that each star traces out a minute annual curve on the sky the greatest radius of which is about 20″. No other cause can account for this aberration of the starlight except the fact that the observatory and the Earth itself are rushing with tremendous velocity through space in a closed curve which takes one year to complete. The rate of motion can be calculated from the angle of aberration, when the velocity of light is known.

The Earth's Orbit.—The regular change in the angular diameter of the Sun seen from the Earth (p. 72) proves that the annual orbit is not a circle, as the two bodies are sometimes nearer and at other times farther apart. The form is an ellipse (Fig. 16), of which the Sun occupies one focus (S); but the ellipse is very like a circle, the ratio of the longest to the shortest diameters being as 100,000 to 100,014. Indeed, a circle 3 inches in diameter drawn with a pencil so sharp as to make a line only $\frac{1}{1000}$ of an inch thick, would represent the orbit correctly, the difference between the ellipse and the circle being concealed by the thickness of the line. The place of the Sun would, however, require to be represented $\frac{1}{40}$ of an inch from the centre of the circle. Certain slow changes take place in the form of the orbit on account of the perturbation of the Earth by other planets. The eccentricity, or distance of the Sun from the centre, increases to a very marked degree, diminishes until the orbit becomes almost a circle, and then begins to increase again. The time elapsing between successive maxima of eccentricity is about half a million years. The Earth moves round this orbit with varying speed, moving fastest when nearest the Sun (or in perihelion, *p*), and slowest when most remote (or in aphelion, *a*); the average velocity is about 18½ miles per second or 66,000 miles an hour. Before Newton proved that the power of gravity would produce precisely this effect, Kepler

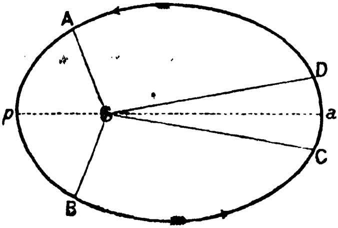

FIG. 16.—Ellipse, representing the Earth's Orbit greatly exaggerated in ellipticity and eccentricity. S, The Sun; *a*, aphelion; *p*, perihelion.

had discovered the nature of the motion, and expressed it in his "Second Law" thus: *The radius vector, or line joining the centres of the Earth and Sun, sweeps through equal areas in equal times.* In Fig. 16 the triangle SAB is equal in area to the triangle SCD; S being the sun, SA, SB, SC, SD, being successive positions of the Earth's radius vector. Hence, since the radius vector sweeps through the angle SAB in the same time as it takes to sweep through SCD, the Earth traverses the long part of its orbit from A to B through perihelion in the same time as it traverses the much shorter distance from C to D through aphelion.

The Year.—The period in which the Earth accomplishes one revolution round the Sun is called a year, and is the unit for long intervals of time. The unit for shorter intervals of time is the solar day or apparent period of the Earth's rotation. Unfortunately these two natural units are incommensurable; the revolution period of the Earth with regard to the stars is not made up of an even number of rotation periods or of solar days, but consists of 365 days, 6 hours, 9 minutes, 9½ seconds. The *tropical year* or time of apparent revolution is 365 days, 5 hours, 48 minutes, 46 seconds; and it is in order to fit in the extra 5 hours and odd minutes that the plan of having an extra day every fourth year (leap year), and omitting it once a century, is adopted. If this were not done, the same period of the year would not occur in the same part of the Earth's orbit at each successive revolution and the seasons would cease to correspond with the months in which they now occur.

Solar and Sidereal Time.—The revolution of the Earth round the Sun once in a year accounts for the solar day or interval between two successive transits of the Sun across the meridian, being nearly 4 minutes greater than the Earth's rotation period or sidereal day. While the Earth is turning once round on its axis it advances so far upon its orbit that nearly 4 minutes of turning more than a complete rotation are necessary to bring the Sun once more on the meridian. Since the Earth moves with unequal velocity in different parts of its course, and its axis is not perpendicular to the plane of its orbit, the day, as measured from noon to noon, varies slightly in its length throughout the year. The average solar day is taken in order to calculate the solar mean time which is always used in ordinary affairs, hence the differences between mean solar time as shown by a clock and apparent solar time as shown by a sundial.

The Ecliptic.—The Earth's orbit always lies nearly in the same plane, because there is no force competent to change its direction. That is to say, the Earth goes round the Sun in limitless space as a boat sails round a ship on the surface of a calm sea. We may imagine the plane to extend beyond the Earth's orbit through all space so that it intersects the dome of stars. The line of intersection is the apparent yearly path of the Sun amongst the stars, and is called the *ecliptic;* the constellations it traverses are the well-known twelve "signs of the zodiac." The plane of the ecliptic in space serves as a standard level, to which other directions may be referred for comparison. It seems most natural that the Earth's axis should be perpendicular to the plane of the ecliptic, but, as has been said, this is not the case. The axis is inclined about 23½° from the perpendicular. We have thus to picture the Earth sailing round the Sun, not "on even keel" but with a list or inclination of 23½°, and with the north end of the axis always pointing toward the same bright star on the celestial dome. This inclination is not absolutely constant, but like the eccentricity of the orbit is subject to slight increase and diminution in long periods.

Eclipses.—Instead of saying that the Earth revolves round the Sun we should, in order to be accurate, say that "the Earth-Moon System" does so; for the Moon shares the annual revolution of the Earth as a point on the tire of a wheel shares the onward movement of the centre. If the Moon's orbit lay in the plane of the ecliptic, the Moon would pass between the Earth and

Sun once every month, and a fortnight later the Earth would cut off the sunlight from the Moon. In other words, at every New Moon there would be an eclipse of the Sun, at every Full Moon there would be an eclipse of the Moon. But the Moon's orbit is inclined at an angle of about 5° to the ecliptic, and it is only when the Moon happens to be at one of the nodes, or points on the orbit where its plane intersects the ecliptic, that an eclipse can take place. From this fact the ecliptic gained its name. Eclipses of the Moon are common occurrences, for they happen several times in a year and are visible from a large area of the Earth's surface, as the Earth's shadow is wide compared with the angular diameter of the Moon. Eclipses of the Sun are more frequent, but are more seldom seen at a given place, being visible only for a comparatively short time and over a limited tract of the Earth's surface, since the Moon's shadow thrown by the Sun is a comparatively narrow cone. When the Moon is at its nearest point to the Earth, in the course of its elliptical orbit, its angular diameter is great enough to conceal the Sun entirely, and the eclipse is said to be total. But when the Sun is at its nearest, its disc appears larger than that of the Moon at its farthest; and if an eclipse occurs in such conditions it is said to be annular, the black disc of the Moon being surrounded by a narrow bright ring of the Sun, like a penny lying on a half-crown.

Solar Tides.—The differential attraction of the Sun on the opposite sides of the Earth has a tide-raising power like that of the Moon (p. 70). But the Sun is so distant that in spite of its vast mass the difference in its attracting power on opposite sides of the Earth, due to the distance of 8000 miles, is only two-fifths as great as the difference in the attracting power of the nearer Moon. At New Moon and at Full Moon the tide-raising power of Sun and Moon is exerted in the same direction, and produces spring-tides in the ocean; the tidal wave rises highest and sinks lowest or has its greatest amplitude. At the quarters, on the other hand, the Sun is raising high water where the Moon is producing low water, and consequently the amplitude is much less, the tidal wave not rising to the average height nor sinking to the average depth. These are called neap-tides, and represent the difference, as spring-tides represent the sum, of the tide-raising power of Sun and Moon.

Precession of the Equinoxes.—The tropical year or apparent time of the Sun's circuit of the heavens is 20 minutes shorter than the Earth's revolution period (p. 76); in other words, if the Sun starts from that point of the ecliptic known as the vernal equinox it will reach it again 20 minutes before completing the annual circuit of the heavens. Thus the equinox seems to be moving slowly along the ecliptic to meet the Sun, and so every year it precedes or comes before its former position, the phenomenon being known as the precession of the equinoxes. The star-dome, not sharing the movement, appears to rotate about an axis at right angles to the plane of the ecliptic, but so slowly that 25,000 years are required for a single turn. Consequently the constellations on the zodiac have ceased to correspond with the "signs" of 30° each which formerly included them. This apparent movement of the heavens must be produced by a real rotation of the Earth in 25,000 years round an axis perpendicular to its orbit. The semi-axis of diurnal rotation thus acquires a slow conical motion like the mast of a boat which is pitching and rolling equally, and the north pole, instead of pointing steadily to the pole star, traces out a circle on the star-dome about 47° in diameter in the course of 25,000 years. The horizontal axis of a gyroscope at rest is at once drawn into a perpendicular position by attaching a light weight to one end. But if the fly-wheel is in rapid rotation, the angle which the axis makes with the perpendicular remains constant, and the weight attached merely sets up a slow rotation of the gyroscope about the perpendicular, the axis of spinning tracing out a circular cone (p. 33). The differential attraction of the

Sun and Moon on the protuberant region about the Earth's equator (p. 53) exerts a force tending to pull the equator into the plane of the ecliptic and make the axis of diurnal rotation perpendicular. Rotation sets up resistance as in the gyroscope, and the attempt to make the Earth "sit upright" results in the very slow rotation about the perpendicular, to which the axis of diurnal rotation preserves the nearly constant angle of 23½°.

The Sun's Surface.—The bright disc of the Sun which we see is termed the *Photosphere*, and although it appears uniform in texture to the eye, the telescope shows that it is finely mottled with brilliant granules separated by a less luminous network. The Sun rotates in about 25 days, but not like a solid globe, and the fact that marks on different parts of the surface move at different rates proves that the photosphere is the surface of a dense and intensely heated atmosphere in which the bright granules are vast luminous clouds. During a total solar eclipse red flames of fantastic form are usually seen projecting beyond the black disc of the Moon, and these *Prominences* may also be observed without an eclipse by an ingenious arrangement of the spectroscope. They consist of great outbursts of intensely heated gas, mainly hydrogen. Prominences have been seen rising to the height of 400,000 miles above the Sun's surface in a few hours, against gravity 27 times as powerful as that of the Earth. This gives us some idea of the terrific violence of the manifestations of solar energy. Down-rushes of comparatively cool gases from the upper regions of the Sun's atmosphere are believed to be the cause of black marks which are often seen on the photosphere and termed *sun-spots*, although sometimes many thousand miles in diameter. Though apparently black, compared with the intense glow of the rest of the surface, sun-spots really shine with a light brighter than that of the electric arc. Photographs of the Sun's disc are taken daily in some observatories in order to preserve a record of the number and movements of sun-spots, and in this way much information has been obtained on the subject. It has been observed that spots usually originate at some distance on either side of the Sun's equator, and for a time they increase in size; then beginning to diminish they travel toward the equator and gradually vanish, being succeeded by others, which are smaller and fewer. Finally, after about twelve years or so, the whole set fades away, and a new series of larger size appears and goes through the same changes. Periods when sun-spots are at a maximum succeed each other at intervals of about eleven years, and relations have been traced between them and the influence of the Sun's radiant energy on the Earth. During total eclipses a halo of silvery light, sometimes circular, sometimes spreading out like great wings, surrounds the Sun. It is called the *corona*, and is probably composed of fine particles of dust either thrown off by the Sun or being attracted toward it and shining, in part at least, by reflected light.

The Spectrum of Sunlight is a brilliant band of colour crossed by an immense number of black lines (the more conspicuous of which are named in Fig. 8), showing that the light from some glowing solid or liquid has reached us after traversing an expanse of cooler vapour. These lines have been identified in most cases, and the substances producing them ascertained. The lines produced by absorption of light in the Earth's atmosphere are best recognised by comparing the spectrum of the Sun low in the sky, when they are strongest, with that at noon, when they are faint. When a body giving out light is in rapid motion toward the observer, the wave-length of the light is apparently shortened and the lines of its spectrum are shifted toward the violet end. In the light of a rapidly receding body the lines are similarly shifted toward the red end. At its equator the Sun's surface is moving 70 miles a minute, toward an observer on one side—from him on the other. By causing a small image of the solar disc to flit across the slit of the spectroscope several times in a second, an observer analyses in quick succession the light from the approaching and receding edges. Consequently the most distinct solar absorption lines are seen to oscillate slightly from side to side, being displaced alternately toward the red and toward the violet, while the lines produced in the Earth's atmosphere remain motionless and can be readily distinguished. The elements which have been detected in the Sun are identical with those found in the Earth; the spectrum shows that they are at an enormously high temperature, and some of the solar lines not yet identified may be due to matter of a simpler form than any known elements (see p. 30). The element helium was known by its spectrum in the Sun for years before it was discovered on the Earth.

The Heat of the Sun.—The temperature of the Sun is higher than any that has been produced on Earth, and it does not perceptibly differ from year to year. If the Sun were a heated solid or liquid globe it would be falling in temperature as it radiated heat, unless the supply were kept up in some way. There is no external source of heat that is sufficient to account for the vast solar expenditure. The collision of meteorites and many other theories have been suggested, tested, and rejected, and we must look to the Sun itself for an explanation. Lord Kelvin and Professor von Helmholtz have shown that as the solar atmosphere loses its heat the power of gravity draws its particles closer together, and this shrinking transforms the potential energy of separation (pp. 35-36) into heat, which is sufficient to maintain the diminished volume at the same or even a higher temperature. The process will go on, loss of heat being compensated, or more than compensated, by shrinkage, as long as the Sun remains mainly gaseous. The discovery of radio-activity, by which the internal energy of the atoms may be transformed directly into heat, deprives this line of reasoning of the value it was formerly believed to have in indicating the age of the Sun or the future duration of its heat.

The Earth's Share of Sun-heat.—Since the Sun's parallax is less than 9″ it follows that, viewed from the Sun, the Earth only occupies $\frac{1}{2000000000}$ of the sky, or a disc 18″ in diameter. The Earth consequently receives less than $\frac{1}{2000000000}$ of the radiant energy sent out by the Sun. If the Sun were expending, instead of energy, money at the rate of £18,000,000,000 a year, the Earth's annuity would be only £9. This endowment, however, is payable continuously, and at the same rate throughout the year, in the proportion of 6d. every day or ¼d. every hour. Minute as the energy which reaches the Earth appears in view of what streams away into space, it is stupendous when compared with the power of the greatest steam-engine ever constructed, and is, indeed, the source of all the work and all the wealth of the world actual and prospective.

Effects of Inclined Axis.—If the Earth's axis of rotation were perpendicular to the plane of the ecliptic the Sun's radiant energy would be dispensed for an equal time each day over the whole surface—every place would always have 12 hours of daylight and 12 hours of darkness. The Sun would always be in the zenith at noon on the equator, but never elsewhere; at the poles (disregarding refraction) the Sun would always be half above the horizon, and at every intermediate point the meridian altitude would always be (as in fact it is at the equinoxes) the complement of the latitude, *i.e.* 90° minus the latitude. In consequence of the inclination of the axis the distribution of radiant energy on the Earth is unequal and varies at different times of the year, giving rise to the *seasons*.

Vernal Equinox.—The position on 21st March (Fig. 17) is such that the equator lies in the plane of the Earth's orbit as viewed from the Sun, and the Sun appears in the zenith at noon viewed from the equator. Sunlight reaches both poles simultaneously, and as the Earth rotates, every place on the surface is lighted up for twelve hours and plunged in darkness for the other twelve, day and night being equal everywhere. This period is therefore called the vernal or spring *equinox*, and happens at that point in the Earth's orbit from which the Sun appears projected on the star-dome in the sign of Aries. This season is spring in the northern and autumn in the southern hemisphere.

Summer Solstice.—In three months, the Earth having advanced along one quarter of its path, the equator dips 23½° S. of the plane of the ecliptic when viewed from the Sun, hence the Sun viewed from the Earth appears at noon in the zenith on the parallel of 23½° N.; and as at this time the Sun is projected on the star-dome in the sign of Cancer, this parallel is called the Tropic of Cancer. This is the highest northern latitude for a vertical Sun, and is called a *tropic* because the Sun appears to *turn* southward after reaching it. Sunlight reaches 23½° beyond the north pole, and falls short of the south pole by 23½°. As the Earth rotates the whole region for 23½° round the north pole keeps in sight of the Sun, the whole region round the south pole rests in darkness, and the period of daylight diminishes while that of darkness increases over the world from north to south, being 12 hours each at the equator. The Sun being vertical at noon, 23½° north of the equator, its meridian altitude from the south point of the horizon in the northern hemisphere is equal to the complement of the latitude plus 23½°. In

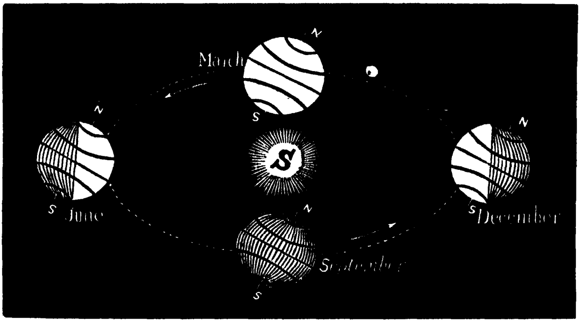

FIG. 17.—Diagram illustrating the Cause of the Seasons.

the southern hemisphere the Sun's greatest altitude is equal to the complement of the latitude minus 23½°. This period is termed the summer *solstice,* as the Sun *stops* in its northern path. It is the middle of the northern summer and of the southern winter. The parallels of 66½° (23½° from the poles) are termed the *Arctic* and *Antarctic Circles,* and, but for refraction, these would be the lowest latitudes in which sunlight or darkness can last for 24 hours at a time.

Autumnal Equinox and Winter Solstice.—In three months more it is the autumnal equinox; the equator comes again into the plane of the Earth's orbit, day and night are equal from pole to pole, and the Sun's meridian altitude is again equal to the complement of the latitude. The Sun is projected on the star-dome in the sign of Libra, and it is the autumn of the northern hemisphere and the spring of the southern. Another period of three months brings the Earth into such a position that the equator is 23½° N. of the Sun's place in the ecliptic, and consequently the Sun is seen vertically overhead at noon from the parallel of 23½° S., which is termed the Tropic of Capricorn after the sign in which the Sun is projected on the star-dome. This is the highest south latitude for a vertical Sun. The Sun is visible everywhere within the antarctic circle, but all within the arctic circle is in day-long darkness. In all parts of the southern hemisphere the Sun's meridian altitude above the north point of the horizon is 23½° greater than the complement of the latitude; in the northern hemisphere the Sun's meridian altitude above the south point of the horizon is 23½° less than the complement of the latitude, and the days grow shorter and the nights longer from south to north, day and night being equal on the equator. This is the winter solstice, midwinter in the northern hemisphere and midsummer in the southern.

Altitude of the Sun.—The altitude of the Sun and duration of daylight are described above for a globe without an atmosphere. On account of refraction (see p. 105) the Sun always appears higher in the sky than its true position; the period of daylight is thus increased and the period of darkness diminished, the effect being greatest in high altitudes.

LENGTH OF THE LONGEST DAY.

Latitude	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
Hours	12	12h. 35	13h. 12	13h. 56	14h. 51	16h. 19	18h. 30	65 days	161d.	186d.
	(Refraction slight and not allowed for)							(Refraction allowed for)		

Between the tropics the Sun is vertical in every latitude twice in the year; outside the tropics never. Even in summer the altitude of the Sun is low in high latitudes; it can never be more than 23½° at the poles, nor more than 53½° in 60° latitude. The amount of radiant energy falling on a unit area of surface varies with the altitude of the Sun. Fig. 18 shows that the same beam of light which, falling vertically, covers 1 square foot of surface, will, when falling at an angle of 30°, cover 2 square feet, and so produce on each square foot only one half of the effect of vertical light; at a lower angle the heating effect of sunlight is very slight. Oblique rays of light also pass through a thicker layer of the Earth's atmosphere, and so are more absorbed than vertical rays.

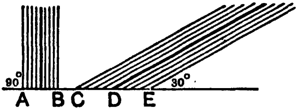

FIG. 18.—Angle of Light Rays. The breadth of the beam CE is the same as that of AB, but striking at an angle of 30° the length CE is twice the length AB where the rays fall perpendicularly.

Zones of Climate.—It follows that the region between the tropics receives most of the solar energy, higher latitudes sharing it in smaller and smaller proportions. The Earth has consequently been divided into zones of climate—a word originally meaning *inclination* of the Sun's rays. The areas within the polar circles, poorest in radiant energy, are termed the *Frigid Zones*, those between the polar circles and the tropics, where there is a tolerable abundance of radiation, the *Temperate Zones*, and the wide belt between the tropics which is overflowing with solar wealth the *Torrid Zone* (Fig. 19). If the Earth were a smooth lithosphere, surrounded by a continuous hydrosphere and atmosphere, this unequal distribution of solar energy would give rise to a regular system of redistribution by currents streaming from the equator to the poles in the upper regions of the atmosphere, and from the poles to the equator in the lower, their paths curved in consequence of the rotation of the Earth ; and in this way the tropical warmth would be distributed with some approach to uniformity over the whole surface. The actual redistribution is much more complicated, as will be seen later.

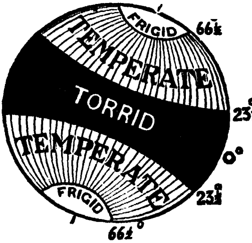

FIG. 19.—Zones of Climate on the Earth.

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CHAPTER VI

THE SOLAR SYSTEM AND THE UNIVERSE

The Solar System.—The Sun and Moon are not the only celestial bodies which pass between our eyes and the dome of stars. Several bright objects, which, unlike the stars, shine without twinkling by light reflected from the Sun and show a distinct disc in the telescope, were long ago called *planets*, or wanderers, for they pursue a devious track among the constellations, changing in position on the star-dome from night to night. All the planets are related to each other, as their wanderings are all confined to the belt of sky termed the zodiac, extending only a few degrees on each side of the ecliptic. The distances of these bodies from the Earth have been measured, and it has been proved that like the Earth they all rotate and revolve round the Sun in elliptical orbits, the planes of which are, as a rule, only slightly inclined to the plane of the ecliptic. Some of the statistics of the members of the solar system are given in the following table.

Inner Planets.—The four planets next the Sun are often called the inner planets. Mercury and Venus are never seen very far from the Sun, and Mercury is rarely visible to the naked eye. **Venus,** visible sometimes as the evening star shortly after sunset, and at other times as the morning star shortly before sunrise, is a magnificent object, its light being often strong enough to throw a distinct shadow. These two planets exhibit phases like the Moon, those of Venus being clearly visible by the aid of an opera-glass. It has been proved that the period of rotation of Venus is equal to its period of revolution round the Sun; and this is almost certainly true of Mercury also. Solar tidal friction has evidently acted on these planets as the tidal friction of the Earth has acted on the Moon; and it is interesting that the two planets nearest to the Sun, and receiving enormously more heat and light than the Earth, have perpetual day in one hemisphere, and perpetual night with a cold approaching the absolute zero in the other. Mercury and Venus occasionally pass between us and the Sun, the planet appearing to pass across the solar disc like a small black spot. A transit of Venus affords the best opportunity of measuring the solar parallax, and hence the Sun's distance, by noticing how far the path of the planet across the disc is altered when viewed from distant parts of the Earth.

THE PLANETS.

Name.	Symbol.	Mean Distance from Sun. Million Miles.	Periodic Time. Solar Days.	Diameter of Planet. Miles.	Rotation Period.	Satellites.
					Days.	
Mercury .	☿	35·9	88	2,976	88 (?)	...
Venus . .	♀	67·3	224·7	7,629	224·7	...
					Hrs. Min.	
Earth . .	⊕	92·7	365·3	7,918	23 56	1
Mars . .	♂	142	687	4,316	24 37	2
ASTEROIDS	...	...	...	...	...	...
Jupiter. .	♃	484	4,332	86,260	9 55	8
Saturn . .	♄	887	10,759	72,770	10 14	9
Uranus. .	♅	1,780	30 586	32,880	...	4
Neptune .	♆	2,796	60,187	29,830	...	1

Mars, the first planet beyond the Earth, most resembles it. The rotation period is nearly the same, and the surface is diversified by marks which evidently indicate continents and seas, while at each pole a gleaming white patch increases and decreases as the planet wheels round the Sun, suggesting the forming and melting of great areas of snow. A network of curious straight markings termed "canals" also show changes which are not yet understood; but they are held by some astronomers to be strips of dense vegetation bordering irrigation channels, and thus affording evidence of the existence of intelligent beings on the planet. Mars has two satellites, discovered in 1877. One is very small, very near the planet, and races round it, from west to east, in little more than 7 hours, making three complete revolutions whilst the planet rotates once; the other, farther away, revolves in 30 hours.

Asteroids.—It had been observed even before Kepler's time that there is a certain symmetry in the placing of the planets. This relation was subsequently formulated by the German astronomer Bode in the end of the eighteenth century, and has since been termed *Bode's Law*. It is as follows: If 4 be added to each member of the numerical series—

0	3	6	12	24	48	96

we get—

4	7	10	16	28	52	100
Mercury.	Venus.	Earth.	Mars.	——	Jupiter.	Saturn.

These figures represent roughly the relative distance of the planets from the Sun, *e.g.* Saturn is about ten times farther than the Earth. There is a gap between Mars and Jupiter, and although no physical reason was, or is, known for this arrangement, the whole system seemed so orderly that Kepler supposed this gap to represent the place of a missing planet. Bode and several other astronomers were so impressed by the gap in this law that they agreed to examine the sky very minutely for the missing planet. While their search was in progress the Italian Piazzi (who was not one of the number) discovered on the first night of the nineteenth century a small planet occupying exactly the position prescribed by this law, and gave it the name of Ceres. In the following year another little planet was discovered, and when half the century had elapsed fifteen had been found. A more systematic search was then commenced by astronomers, and many more were discovered. They are so like stars that the name Asteroid (star-like) is frequently given them. In recent years a systematic photographic survey of the heavens has been undertaken, in the course of which the number of minor planets had been increased to 600 by 1910, and new ones are still being discovered each year. All of these, except three or four, have orbits falling between those of Mars and Jupiter. These minor planets are all very small, the largest being probably only 300 miles in diameter; the orbits of some are very long ellipses, and lie far out of the plane of the ecliptic (compare p. 93).

Outer Planets.—Beyond the thick part of the asteroid ring the giants of the solar system, each attended by a train of satellites, rotate with amazing speed, and are surrounded by thick atmospheres loaded with heavy clouds. **Jupiter,** the largest of all, with four large and four very small satellites, has a temperature so high that dense layers of cloud, arranged in belts parallel to the equator by its rapid rotation, completely obscure the body of the planet. The spectrum of its light shows some dark bands which are not due to reflected sunlight, and it has been assumed that Jupiter is only now cooling down from being a self-luminous body. **Saturn,** although somewhat smaller, is unique in being accompanied by a series of rings or thin flat discs surrounding its globe parallel to the equator, and reflecting sunlight like the planet itself. These rings can only be accounted for on the assumption that they are composed of orderly crowds of innumerable minute satellites. Outside the rings there are nine separate satellites of various sizes.

Uranus and Neptune.—Uranus has been known as a planet since 1781, when it was discovered by Herschel. One astronomer had observed it previously twelve times, and only the careless way in which he kept his notes prevented him from recognising it as a new member of the solar system. This remote body is remarkable for its four satellites revolving in apparently circular orbits in a plane at right angles to that of the planet's orbit. The movements of planets in their orbits under solar attraction is calculated from Kepler's Laws (p. 75), but allowance has always to be made for the perturbations or deviations produced by the attraction of other planets. After all possible allowances were made, and the path of Uranus along the star-dome calculated, it was found that the planet did not keep to its time-table. The English astronomer Adams and the French Leverrier made calculations on the assumption that this irregularity was produced by an unknown planet beyond Uranus. In 1846 their work was finished almost simultaneously, and each predicted the position of the hypothetical planet in the sky. The very day that the information from Leverrier reached the observatory of Berlin, the German astronomer Galle turned his telescope to the part of the sky indicated, and there discovered the new planet which was named Neptune. Like Uranus it had previously been recorded as a star, and it was only by mistrusting his observations that an earlier astronomer failed to detect its true nature. One satellite has been observed which revolves, like the outermost satellites of Jupiter and Saturn, from east to west, opposite in direction to the other planets and satellites.

Comets.—Occasionally a luminous body appears in the sky, brighter in some cases than the planets, and usually enswathed in a long flowing tail of gauzy texture, from which peculiarity it is called a comet. Many comets have been found to travel in elliptical orbits, much more elongated than those of the planets, but like them with the Sun in one focus. As a comet pursues its path, it approaches the Sun with increasing velocity, sweeps round and sometimes almost touches the solar surface, and then flies on with ever diminishing speed to its aphelion. Halley's comet was the first the regular return of which was noticed ; its period is 76 years, and it last returned to perihelion in 1910, when it passed within the Earth's orbit, but its aphelion lies outside the orbit of Neptune. Several comets have their farthest points from the Sun near the orbit of Neptune; others show a similar relation to Uranus and to Saturn, while quite a number of comets of short period are associated with the orbit of Jupiter. Many of the grandest comets that have been seen pursued a path shaped like a parabola or hyperbola, and after passing the Sun swept out of the solar system for ever. It is supposed that the orbits of comets are naturally parabolas, but when the comet happens to pass near enough to a planet the path is changed by attraction either into a closed curve —an ellipse—or into a hyperbola. Comets are thus viewed as the carriers of new stores of matter and energy into the solar system from remoter realms of space. Halley's comet is believed to have been captured by the attraction of Neptune when it was sweeping through the solar system, and the other periodic comets are similarly the slaves of the great planets. The planes of the orbits of comets show no common relation to that of the ecliptic, sometimes indeed being perpendicular to it. To revert to a former simile (p. 77), if the Sun be compared to a large ship, and the ecliptic to the surface of the ocean, steam-launches manœuvring round the ship represent the planets, all nearly in the same plane, though the swell of the ocean causes them to be above the mean level at one part of their evolutions and beneath it at another. A comet would be represented by a diving bird going round the ship by diving under the keel and flying above the deck.

Nature of Comets.—The tail of a comet, sometimes several million miles long, is greatest when near the Sun, away from which it points whether the comet is approaching or receding. Comets shine, according to the spectroscope, partly with reflected sunlight and partly with the light of glowing vapour. The density of their substance is very slight, and they were long supposed to consist of masses of glowing gas. Recent observations, however, make it almost certain that they are swarms of very small solid bodies far enough apart to let starlight pass between them, and these when heated by approach to the Sun give off vapour at first composed of a compound of carbon and hydrogen, latterly, as the temperature is higher, of metals such as sodium and iron. The particles which make up comets may be only a few inches, or possibly only the fraction of an inch in diameter.

Meteors.—Attentive observers may see a few meteors or "falling stars" on any clear night. A star apparently detaches itself from its neighbours on the star-dome and silently glides downward, sometimes leaving an evanescent track of light. At certain times, particularly about 10th August and 13th November, this phenomenon is so common that showers of shooting-stars are seen. At those dates the Earth crosses the orbits of two comets. The November shower is sometimes magnificent, and for a century the grandest displays recurred at intervals of about 33 years. The display of 1866 is still remembered, but that of 1899 was quite insignificant. Meteors are not falling stars, for the stars are as numerous after a meteor shower as before. They are produced by small solid bodies, on the average perhaps as large as a pea, which enter the Earth's atmosphere with enormous velocity. The energy of motion is converted into heat by the friction of the air, and the solid is immediately driven into vapour and vanishes, being condensed into fine invisible dust (p. 113). Meteors usually begin to glow at the height of about 80 miles above the Earth's surface, and die out at the height of at least 50 miles.

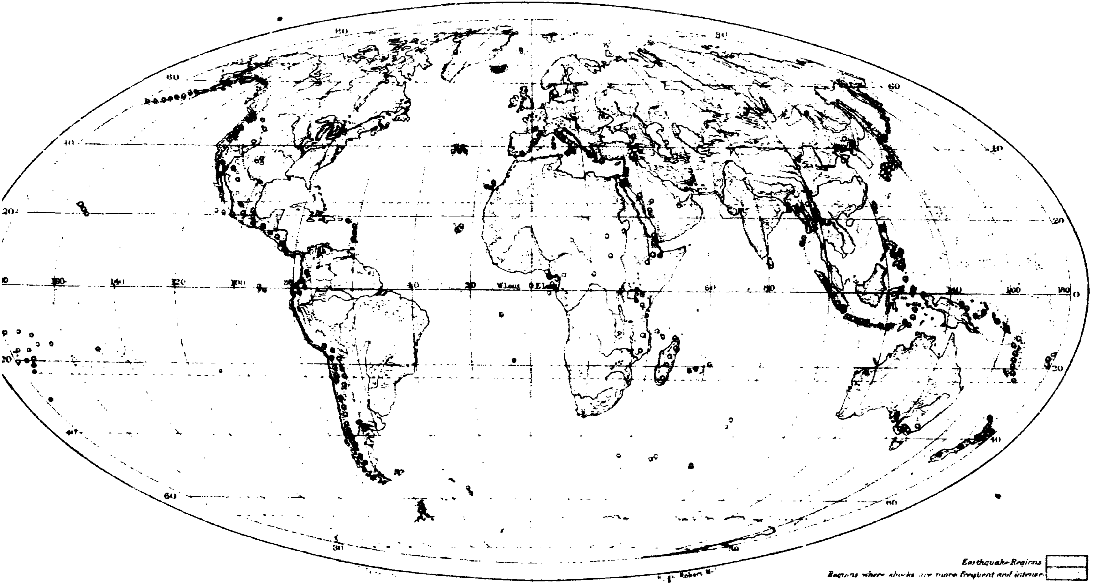
Meteorites.—It has occasionally happened that meteoric masses of considerable size, weighing many pounds or even hundredweights, have fallen on the Earth, and in a number of cases this has happened in the sight of intelligent witnesses. Meteorites, as such masses are termed, are of at least two classes—

either metallic composed mainly of iron and nickel, or stones resembling volcanic rock, although frequently associated with minerals not known in terrestrial rocks. They often contain carbon, and almost always considerable quantities of various gases absorbed in their pores. When a powdered meteorite is heated in a tube from which the air has been exhausted, and through which an electric current is passed, it glows with a faint light, the spectrum of which is very like that of comets, strongly confirming the meteoric theory of those bodies (p. 113). The close relation of meteors and comets was proved very forcibly in 1861 when the Earth dashed through the tail of a comet; again in 1872, and in 1885 when Biela's comet was calculated to cross the Earth's orbit close to the Earth's place at the time. The only sign of the collision on these occasions was a fine shower of shooting-stars, through which the Earth sailed as safely as a locomotive passes through a cloud of dust. Meteorites of all sizes, from an invisible granule to masses of several tons, and moving in various directions, seem to be scattered in infinite numbers through all space, and occasional denser swarms moving together form comets.

The Stars.—The Sun, surrounded by its orderly family of planets and an irregular host of attendant comets and meteorites, is practically alone in the centre of the star-sphere, forming one system isolated by inconceivable expanses of space from the fixed stars. But the Sun and its train are sweeping with tremendous velocity in the direction of the constellation Hercules. The number of stars or fixed points of light on the star-dome which are visible at any one time to the unaided eye of an observer on the Earth is about 3000. More people in fact assemble to hear a popular concert than there are stars in the heavens, so far as our vision can tell. By the aid of an opera-glass more than 120,000 stars, too feeble in their light to be seen by the unaided eye, spring into sight. A million may be seen through a small telescope; in a large telescope the number is enormously increased, and with every instrumental improvement smaller specks of light crowd in myriads on the view. Some stars, invisible in the most powerful telescopes to the eye, have been discovered by their effect on a sensitive photographic plate. Altogether the existence of something like 100,000,000 stars has been ascertained. The telescope, no matter how powerful, fails to make even the brightest star appear as a disc; but it often shows that what we see as a single star is actually double, triple, quadruple, or multiple. In some cases this is an accidental result of stars, perhaps very distant from one another, lying nearly in the same line as seen from the Earth; but there are many "physical doubles," the associated stars of which are seen to revolve round one another. This discovery proves that these stars are subject to gravitation. Several stars vary in their brightness at definite intervals, at one time blazing out with extraordinary brilliance and then fading down to invisibility. This happens so regularly in some as to suggest that a dark body revolving round the star comes between it and us. In other stars the increase in brightness is accompanied, according to the spectroscope, by a change in chemical constitution and a great increase of temperature, as if perhaps swarms of meteorites flying in opposite directions had come into collision.

Distance of the Stars.—The stars are so remote that when corrected for aberration (p. 74) there is, as a rule, no apparent parallax. This means that the displacement of our eye by 186,000,000 miles from one side of the Earth's orbit to the opposite does not alter their apparent position on the star-dome. In several cases a minute parallax has been measured. The largest, only three-quarters of a second of arc, is that of α Centauri, one of the brightest stars visible in the southern hemisphere. The parallax of Sirius, the brightest star in the sky, is one-third of a second, that of the Pole Star only $\frac{1}{16}$ of a second. Light which travels at 186,000 miles per second requires 8 minutes

EARTHQUAKE REGIONS AND VOLCANOES.



to flash from the Sun to the Earth, and would require 9 hours to traverse the diameter of Neptune's orbit. Yet the light from α Centauri, the nearest star, has been nearly 4 years on its way to us. We see Sirius by the rays sent out more than 9 years ago, and for nearly half a century the light-waves which are now arriving from the Pole Star have been shooting with lightning speed across the awful voids of space. Other stars are perhaps a hundred or a thousand times more remote than these. Although the star-dome may be spoken of as a vastly distant whole with reference to the solar system, it is really made up of remotely isolated objects placed at different distances and seen by us at different dates. For all our sight can tell us to the contrary, every star that shines placidly in the sky may have grown cold years or centuries ago, and snapped the thread of light, the end of which may now be fast approaching our Earth.

Stars as Suns.—For classifying the stars the spectroscope has entirely superseded the telescope. By its means great differences have been detected in the chemical composition and physical states of various stars, and the classification now viewed with most favour is of a biographical character, referring the star to its position in the long evolution or series of changes through which our Sun is passing (p. 82). In arranging the stars in the order of their evolution their state at the period their light left them is of course referred to. Stars of youth, or the earlier stages, are comparatively cool and diffused agglomerations of matter gradually condensing and rising in temperature. Stars of middle life, or the central stages, are intensely hot, invested with a glowing atmosphere of gas which gives bright lines in the spectra of their light. Stars of old age, or the later stages of evolution, have survived the period of maximum temperature and are steadily consolidating and cooling down. There is reason to believe that many stars are invisible to us because they have ceased to glow. We may infer, from their general similarity to our Sun, that stars of the central and later stages at least are accompanied by systems of planets. Some double stars present much the same appearance as the Sun would have done at a similar distance when Jupiter was still brilliantly incandescent. Many of the stars have a rapid motion through space as shown by the displacement of their spectral lines. This is termed their proper motion, to distinguish it from the various apparent movements, but though it is inconceivably swift it has produced very little change in the appearance of the constellations in 2000 years.

Charting the Heavens.—Although the constellations remain of the same form as when first described by astronomers, some change must be taking place. Common star-maps fail to let the changes appear, but a series of large photographic charts of the sky would probably show a definite alteration of position amongst the stars on account of their proper motion in a few years. A complete photographic chart of the heavens was undertaken by international agreement in 1887, the task being divided between eighteen observatories. Each photographic plate covers a portion of the sky measuring 2° by 2°. In order to prevent confusion from chance specks and to detect asteroids, a device has been adopted by which the photographic plate is exposed in the telescope in three stages with a slight shift of position in each. Each bright star thus prints itself as a little triangle of three points, while in consequence of its relative motion an asteroid presents its record in one little blurred streak and can thus be readily detected.

Form of the Universe.—On a clear moonless night a luminous gauzy band called the Milky Way may be seen spanning the sky like a wide but ragged and colourless rainbow. As this is visible from all parts of the Earth it evidently forms a complete girdle round the star-dome. A telescope of moderate power shows that the Milky Way is really a dense pavement of stars. There is no reason to believe that any two of these stars are nearer each other than the Sun and *a* Centauri, and the apparent crowding is simply an optical effect due to their great number. If we were led blindfolded into a regular pine plantation, and on looking round found that to east and west the tree-trunks stood out sharply against the sky, affording a glimpse of diversified country beyond them, while to north and south the trunks were crowded so closely that they formed merely a reddish mist under the dark green leafage, we would naturally conclude that the wood was planted in a long narrow belt running north and south. So from our station in the Universe the Milky Way appears as the direction in which the extent of star-sown space is greatest; the widely strewn stars indicate the sides on which it is least. The form of the Universe, if this mode of reasoning be correct, is that of a vast disc, the edge of which, as shown by a division in the Milky Way, is partially split and bent back. Within this expanse the great family of 100,000,000 or more stars is supposed to be clustered together, and separated by incalculable distances of vacancy from other universes which may exist.

Star-clusters.—As one might catch glimpses of other forests through the tree-trunks on either side of the long plantation, so we catch glimpses of remote universes through the thinly star-sown regions remote from the Milky Way. These are faint patches of light, which were long called *Nebulæ* from their cloudy appearance. Generations of astronomers have laboured to discover the nature of these cloudy tracts, and in many cases they have succeeded in showing them to be clusters of immeasurably remote stars. The forms of these star-clusters or remote universes are in many cases wonderfully beautiful—ring-shaped, oval, rod-like, or resembling dumb-bells or spirals of much complexity.

Nebulæ.—The old observers were accustomed to find that many nebulæ which their telescopes only showed as a gauzy cloud were resolved into star-clusters when a more powerful instrument was brought to bear on them. Consequently it was long believed that all unresolved nebulæ were simply star-clusters that larger telescopes could make plain. When Sir Wm. Huggins first succeeded in observing the spectra of the unresolved nebulæ in 1864 he detected bright lines unlike those of stars, and doubtless coming from intensely heated gases. They show amongst others the lines of hydrogen, helium, and of an element unknown on the Earth which has been called nebulium. The nebulæ were therefore supposed to be distant masses of glowing gas. Sir Norman Lockyer subsequently suggested a somewhat different explanation of the spectrum. He pointed out that the spectra of nebulæ and of comets' tails and of meteorites in a vacuum tube (pp. 93-94) are all so much alike that they are probably produced by the same materials. Following an earlier suggestion of Professor P. G. Tait, he views a nebula as a vast swarm of meteorites moving in different directions, and by dashing against each other producing heat enough to drive a part of their substance into luminous vapour.

The Nebular Hypothesis.—The Prussian philosopher Kant and subsequently the French astronomer Laplace accounted for the origin of the solar system by supposing that at one time in the remote past it consisted merely of a vast nebula or cloud of intensely hot gas extending far beyond the orbit of the outermost planet. As this cloud cooled and contracted it acquired a whirling motion from west to east, and formed a rotating gaseous disc which gradually condensed at the centre to form the embryo Sun. The edge of the whirling disc was thrown off as a ring by centrifugal force, and the ring ultimately condensed into the planet Neptune. The gaseous disc continuing to contract and to spin more rapidly threw off another ring which gave rise to Uranus, and so on with the other planets, which themselves by a similar process threw off rings to persist like those of Saturn or to condense into satellites. The ring thrown off after the formation of Jupiter, instead of condensing into one planet, consolidated, perhaps on account of perturbation by its great neighbour, into separate bodies —the asteroids. The residue of the original nebula remained as the great globe of the Sun.

Meteoritic Hypothesis.—Sir Norman Lockyer has pieced together the facts discovered by modern astronomers, and he believes them to countenance the theory that originally all space was filled with matter in its simplest or primary form, that this matter commenced to aggregate under the influence of gravity and chemical affinity, producing a fine moving dust of the elements and latterly of their compounds. This dust condensed farther and gave rise to meteorites in great moving swarms separated by tracts of empty space. As the meteoritic swarms shrank by gravity, collisions between the individual meteorites became more frequent, and some of their energy of motion was changed to heat which partly vaporised them, giving rise to the bodies we recognise as nebulæ or as variable stars. These swarms of moving meteorites present many of the properties of a gas on a very large scale, and the motion and equilibrium of a meteoritic nebula would be very similar to those of a gaseous one. Meteoritic material is supposed to pass from the nebular state into that of separate and much denser suns surrounded by families of planets somewhat in the manner Laplace suggested. Lockyer differs from Laplace in making gravitation and molecular attraction the primary cause rather than heat, and so including in the theory the heating up as well as the cooling down of the Universe.

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CHAPTER VII

THE ATMOSPHERE

The Ocean of Air.—We live and move at the bottom of a shoreless ocean of invisible fluid to the surface of which we are powerless to rise. The existence of this ocean is revealed to us by its power of exercising pressure, but the substance composing it was long supposed to have no weight, and the phrases "light as air," "an airy nothing" are remnants of that idea. The simple experiment of inverting a tumbler over a cork floating in a basin of water shows that air can exert pressure and that it occupies space. By means of the air-pump a glass vessel can be nearly emptied of air, and on weighing it before and after emptying, it is ascertained that a pint of air has the mass of about 10 grains, or a cubic foot that of 1¼ ounce.

The Barometer.—Torricelli, an Italian mathematician of the seventeenth century, when investigating the action of the common suction-pump, made a discovery which laid the foundations of scientific knowledge of the atmosphere. He took a tube closed at one end and about 33 inches long, filled it with mercury, and placing his thumb on the open end inverted it (Fig. 20) in a basin of mercury. The column of mercury in the tube sank gradually and stood just 30 inches above the level of the mercury in the basin. Mercury placed in a tube open above and below and set in the same manner would immediately run out by its own weight. Torricelli argued that the only difference in the mercury in the closed tube was that the weight of the atmosphere could not press upon it. He knew that in a liquid at rest every point in the same horizontal plane must be at the same pressure, so he argued that every point in the line *a b* (Fig. 20) must be at the same pressure. The points between *c* and *d* were pressed upon by the weight of 30 inches of mercury, but were free from the weight of the air, while the points from *a* to *c* and *d* to *b* were free from the weight of mercury, but subject to the pressure of the weight of the air. Thus the pressure of the atmosphere on a given area is equal to the weight of 30 inches of mercury, or 14¾ pounds if the given area be a square inch. This reasoning proved that the atmosphere presses as heavily on the Earth's surface as if it were an ocean of mercury 30 inches deep, or, since mercury is about 13½ times denser than water, an ocean of water 34 feet deep. Exact observation shows that the column of mercury balanced by the atmosphere at sea-level over the whole Earth averages 29·9 inches, and it is calculated from this that the whole mass of the atmosphere is 5500 million millions of tons. Since the mercury tube enables one to measure the weight of the atmosphere it has been called the Barometer.

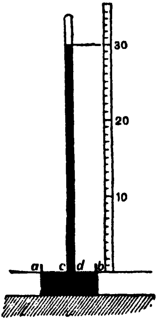

FIG. 20.—Mercurial Barometer and Yard Measure.

Pressure of the Atmosphere.—Torricelli's experiment made it clear that the piston of a common suction-pump lifts the atmosphere from above the piece of water in which the pipe dips, and that the pressure of the atmosphere on the rest of the surface forces up the water over that space until the weight of the column is equal to the pressure on an equal area of the free surface: this height never exceeds about 34 feet, which is the limit of lifting-power in a pump. Air, and fluids generally, exert pressure equally in all directions; and on account of this uniform pressure of the air all round us and through the tissues of our bodies, we do not feel the pressure to which we are always subjected of 14¾ pounds on every square inch, or 14 tons for the whole body of a man of ordinary size. From this cause alone a limpet weighing perhaps half an ounce would stick to a smooth level rock as if its weight were from 10 to 15 pounds, because the soft tough foot is planted so closely on the stone as to exclude all air from below and the pressure comes from the outside only. The limpet sticks as firmly to a vertical or an inverted surface as to a horizontal one. The vacuum-brake is a powerful illustration of the pressure of air, for by it the pressure of the atmosphere applied to a very small part of the surface of a rapidly moving train brings it to a stand in a very short time.

Density of Air.—The mass of the air has been measured with great accuracy, but the height to which it extends, the depth of our aerial ocean, is difficult to estimate. If the density of the air ocean were uniformly the same as it is at the Earth's surface (about $\frac{1}{800}$ of the density of water), its height would be five miles. That this is not the case has been proved by airmen who have frequently ascended to a greater height, and by the use of free balloons which have risen to 18 miles in the air, the pressure and therefore the density of which has been found to diminish steadily as the height increases. But the fact was known by theory centuries earlier. Boyle, in 1662, announced the discovery of the law known by his name:—

The density of any gas is proportional to the pressure it supports.

The pressure of the atmosphere produced by its own weight is greatest on the Earth's surface or in a mine, where the density is accordingly greatest also. As one ascends in the atmosphere the pressure falls steadily, because less air remains above, and the density of the remaining air is consequently less. Thus the barometer can be used to measure heights: near sea-level a fall of one inch in the barometer corresponds to a rise of 1000 feet. One half of the atmosphere lies beneath the height of 3½ miles, or 18,500 feet, from the Earth's surface, and the half which is above this height can exert a pressure only equal to about 15 inches of mercury at that level. Another rise of 3½ miles (to 7 miles) leaves half of the half atmosphere below, and only one quarter above, the pressure being equal to 7½ inches. At 10½ miles above the Earth's surface ⅛, at 14 miles $\frac{1}{16}$, at 17½ miles $\frac{1}{32}$, and at 21 miles only $\frac{1}{64}$ of the atmosphere lies at a higher level: at 21 miles the barometer would stand at half an inch. Thus, if Boyle's law holds good the atmosphere has no definite limit, but extends with diminishing density throughout infinite space, though practically the rapidity of the reduction of pressure shows that above 50 miles there is only one twenty-thousandth of the mass of the air.

Height of the Atmosphere. — Observations of twilight (p. 115) show that the atmosphere is not less than 45 miles high. The aurora, which is produced in the upper atmosphere (p. 126) has been measured at more than 100 miles above the Earth, and meteors (p. 94) sometimes become visible at 200 miles. Hence it is probable that some vestige of an atmosphere exists at least 200 miles beyond the Earth's surface; but in consequence of its compressibility nearly three-quarters of the whole mass of air lies between sea-level and the summit of the loftiest mountain.

Atmospheric refraction.—When light from any of the heavenly bodies enters the atmosphere, it traverses denser and denser layers, and is consequently bent downward from a straight line as it approaches the surface (p. 39). The amount of this bending or *refraction* is proportional to the obliqueness of the rays of light—thus when the light falls perpendicularly from the zenith there is none, but when it comes parallel to the horizon the refraction is great. A person always refers an object to the direction from which the light enters the eye. When the Sun is near the horizon its light is bent into the curve SA (Fig. 21), and as the light reaches the eye of an observer at A from the direction S′A, he sees the Sun's image at S′, considerably higher in the sky than it really is. In astronomical observations it is necessary to correct this error, and tables of refraction at every altitude of a star and for different temperatures of the air have been compiled. The atmosphere, by raising the apparent position of the Sun, thus serves to lengthen the period of sunlight by about four minutes on the equator, and by several hours and even days in very high latitudes. For a similar reason the midnight sun is visible in places where it would not appear above the horizon if there were no atmosphere. Thus at Archangel in lat. 64° 32′, nearly 2° south of the Arctic Circle, there is perpetual sunlight for several days at midsummer, and at the Pole where but for refraction there would be a six months' day followed by a six months' night there is really a day of nearly seven months and a night of little more than five. When from unequal heating or other causes the distribution of density in the atmosphere becomes irregular, light is reflected and refracted by the layers of air in such a way as to make objects at a great distance visible as if near at hand. This effect, which is most marked in deserts and at sea, is called *mirage*. All our knowledge of the outer regions is obtained by looking through the window-pane of air which encloses the world, and allowance must always be made for its imperfections.

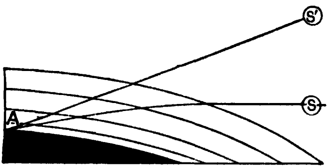

FIG. 21.—Atmospheric Refraction. A, observer; S, true position; S′, apparent position of Sun. The density of the atmosphere is indicated by the closeness of the lines.

Composition of Air.—The experiments of Priestley, Black, and Rutherford at the close of the eighteenth century proved that common air is a mixture of several different airs or gases, and at that date it ceased to be considered an element. Innumerable analyses of air have since been made which show that in all parts of the world the atmosphere has almost the same composition. Traces of nearly every gas which exists naturally, or is produced artificially in large quantities, have been found in air, but the main constituents are few. A rough analysis of air may be made thus:—(*a*) A large tightly-corked flask of warm air when chilled by being covered with snow or ice is seen to become dewed on the inside with liquid drops. These drops are *water*, and their appearance proves that water-vapour is a constituent of air. When a person wearing spectacles steps from the frosty night into a warm room he is the victim of an irritating variation of this experiment, for the cold glasses immediately condense a blinding film of dew-drops from the air. (*b*) When a little clear lime-water is shaken in a flask of air the liquid becomes milky from the formation of solid carbonate of lime, a compound of carbonic acid with lime. Hence, *carbonic acid* is one of the constituents of air. (*c*) When a candle, or a piece of charcoal, or of phosphorus is allowed to burn in a limited quantity of air under a tumbler or bell-jar inverted in water, the flame soon goes out, and another bit of burning charcoal, or phosphorus is extinguished the moment it is introduced; moreover, the water rises until it fills about one-fifth of the jar, showing that about one-fifth of the atmosphere is a gas which is consumed by burning substances. This gas is *oxygen*. (*d*) The air from which burning phosphorus has extracted the oxygen is mainly a gas called *nitrogen* with no striking properties. (*e*) When a sunbeam traverses a darkened room, or when strong sunlight streams through an opening in a thick cloud, immense multitudes of motes may be seen dancing in the light. Thus *dust* is seen to be an ingredient of the atmosphere. The amount of water-vapour is variable, and the amount of dust is still more uncertain; but the other constituents occur thus:—

	By weight.	By volume.		
Nitrogen . . .	76·03	78·21	or	$\frac{4}{5}$
Oxygen . . .	23·14	20·96	or	$\frac{1}{5}$
Argon . . .	0·77	0·79	or	$\frac{1}{125}$
Carbonic acid . .	0·06	0·04	or	$\frac{1}{2500}$
Total . .	100·00	100·00	or	1

Nitrogen and Argon.—Nitrogen has no colour, no taste, no smell, no tendency to combine with other elements, no poisonous effect on living creatures, and no power to keep them alive. From the last circumstance it is sometimes called *Azote.* Not until 1894 was it discovered that a still more inert gas, Argon, formed $\frac{1}{100}$ of the volume of air from which oxygen was removed. The use of nitrogen is mainly to produce mechanical effects. Most of the pressure of the atmosphere, the strength of wind, the refraction of light, and the buffer-action which breaks the force of meteorites and drives them into dust, is due to nitrogen. When an electric discharge passes through air, a small quantity of nitrogen is always caused to combine with hydrogen and oxygen to form nitrite or nitrate of ammonia.

Oxygen was originally known as *Vital Air*, for it is the ingredient of the atmosphere which sustains life, and by its ready combination with other elements supports combustion. The oxygen of the atmosphere is a great store of potential energy when taken into account with the uncombined substances in the Earth (pp. 27, 36). Oxygen in the pure state combines very energetically with carbon, hydrogen, and almost all the other elements; but when it is diluted with four times its volume of inert nitrogen, combustion is slower and quieter, although the same amount of energy is ultimately set free as would be the case if no nitrogen were present. Under the influence of electric discharge, and of the growth of some trees, oxygen is partly changed into a condensed form called *ozone*, and partly combined with water to form peroxide of hydrogen. These substances may exist in the air in very minute proportions, but it is not certain that the presence of either increases the healthfulness of a neighbourhood. Oxygen in small quantities is a colourless and transparent gas, but in the atmosphere it absorbs a good deal of sunlight, giving broad black bands in the red part of the spectrum. The blue tint of the sky may be due in part to the true colour of oxygen.

The proportion of oxygen in the free air of the country is a very little greater than in crowded towns.

Carbonic Acid, though present in small amount, has an important part to play in the economy of the atmosphere. Green plants in sunlight absorb it, decompose it, retain the carbon to build up in their own substance, and breathe back the oxygen into the air. Animals and also plants of every kind breathe in air, absorb the oxygen, which is ultimately combined with carbon and breathed out as carbonic acid. There is a large proportion of carbon in coal, oil, wood, fat, and almost all combustible substances, which thus produce carbonic acid as the principal result of their union with oxygen. The amount present in the atmosphere varies considerably ; 3 parts in 10,000 is the proportion in the open country, 5 parts is common in towns, and as much as 30 parts of carbonic acid in 10,000 of air may be found in badly-ventilated overcrowded rooms. More than this proportion acts poisonously on animal life. Carbonic acid is the most soluble of the atmospheric gases, water at 60° F. and under ordinary pressure absorbing its own volume.

Mixture of Gases.—One consequence of the nature of gases is that when two or more different kinds are mixed, each one acts as if it alone were present. This is known as Dalton's Law. Thus there is an atmosphere of nitrogen surrounding the globe, and exerting the pressure of its weight upon the Earth's surface, an atmosphere of oxygen pressing upon the surface with its weight, which is rather less than ¼ of the pressure exerted by nitrogen, and very thin atmospheres of argon and of carbonic acid exerting very feeble pressures. There is also an atmosphere of water-vapour pressing with its independent weight on the Earth's surface, and all these partial pressures together make up the pressure exerted by the whole atmosphere. The particles of the different gases pass each other freely, without interfering, like crowds moving in different directions across a market-place. Thus the composition of the atmosphere as a whole remains nearly constant for the permanent gases. The proportion of oxygen is slightly less in the tropics, and that of all the heavier gases is distinctly less at great heights in the atmosphere. Above 60 miles the extremely rarefied remnant of an atmosphere is believed to consist almost entirely of hydrogen.

Water-vapour.—Next to oxygen, water-vapour is the most important ingredient of the atmosphere. The other gases are a long way above their liquefying point, so that the addition or withdrawal of heat only affects their temperature and their volume. But water-vapour in the atmosphere is near the temperature at which it becomes liquid or solid, and is nearly always in the presence of liquid water, hence changes of temperature greatly affect the amount of vapour present. Let us suppose for a moment that the atmosphere consisted of water-vapour only, and that the hydrosphere covered the Earth uniformly with a liquid layer. The amount of this atmosphere, and consequently its pressure, would depend upon the temperature. Evaporation takes place from cold water, or even ice, but at every temperature when the vapour exerts a certain definite pressure upon the liquid, evaporation is stopped, and the vapour is said to be saturated at that temperature.

Water-vapour and Temperature.—At the freezing-point (32°) water-vapour is saturated, *i.e.* presses sufficiently to stop evaporation, when its pressure is equal to that of 0·18 inch of mercury; at 50° it must exert twice this pressure, or 0·36, before evaporation ceases; at 70° it must exert a pressure of 0·73, and at 90° a pressure of 1·45 inches, in order to be saturated. These figures show that at 50° twice as much vapour is required to form a saturated atmosphere as at 32°, and at 70° twice as much as at 50°, and at 90° twice as much as at 70°. If an atmosphere of water-vapour saturated at 50° is warmed up to 70°, evaporation is at once allowed to commence and will continue until the amount of vapour present above the water is doubled. Then the vapour will exert pressure sufficient to stop further change, and will be saturated. Again, if the temperature of the saturated vapour is reduced from 70° to 50°, half the vapour must return to the liquid state or become condensed in order that the pressure may fall to that which is just sufficient to prevent farther evaporation. Hence it is plain that every rise of temperature is accompanied necessarily by evaporation, every fall of temperature is accompanied necessarily by condensation, until the vapour exerts the pressure proper to its new temperature. Precisely the same thing happens, as explained by Dalton's law, when there are atmospheres of nitrogen, oxygen, argon, and carbonic acid round the Earth. The pressure of saturated water-vapour at 50° is still equal to 0·36 inch of mercury,—the only difference is that it takes a longer time for the pressure to readjust itself to a change of temperature, as a party of excursionists crossing a broad railway platform reach their carriages, whether the platform is left to themselves or is thronged by crowds moving in different directions, only in the latter case the transference takes a longer time. On account of the low temperature at great elevations, water-vapour, although its density is little more than half that of air, is almost entirely confined to the lowest region of the atmosphere.

Vapour Pressure and Humidity.—The fraction of atmospheric pressure exerted by the water-vapour it contains is often termed *vapour tension*, but preferably vapour pressure. The amount of water-vapour in the atmosphere at any place as measured by the hygrometer, and expressed either as the pressure it exerts in inches of mercury or else as the number of grains weight in a cubic foot of atmosphere, is called the *absolute humidity*. In the case of saturated vapour this depends only on the temperature. The vapour in the atmosphere has seldom an opportunity to become saturated, for the air is never at rest. Suppose, for example, that air containing water-vapour saturated at 32°, and therefore exerting a vapour pressure of

0·18 inch, is carried inland to a waterless place and heated up to 50°. Or suppose simply that its temperature is raised so rapidly that the somewhat slow process of evaporation has not had time to produce its full effect. The absolute humidity or vapour pressure is consequently only 0·18 inch, but evaporation could continue if time and opportunity were given until the amount of vapour would be doubled. Hence this portion of the atmosphere has only one half, or 50 per cent., of the water-vapour it could contain at its temperature. If the same portion of air were cooled without other change to 32° it would contain all the vapour possible at that temperature, or 100 per cent., and have no tendency to evaporate more. If it were heated to 70° it would contain only one quarter, or 25 per cent., of what might be present at that temperature, and evaporation would go on rapidly from free surfaces of water. The term *relative humidity* is applied to the percentage of the whole possible amount of water-vapour which is present at any particular temperature. When the relative humidity is low the atmosphere is "drying" or has a tendency to raise more vapour from water or damp soil; when on the other hand the relative humidity is high, there is little tendency to evaporation, and a slight fall of temperature leads to saturation and condensation.

Thermal Changes in Evaporation and Condensation.—The change of a pound of water into a pound of vapour requires just the same expenditure of energy (p. 46), whether it takes place in a kettle boiling on a fire, or over the surface of a freezing pond. The work of evaporation uses up heat, and produces a lowering of temperature. On the other hand, when vapour is condensed to the state of water, the potential energy stored up is reconverted into heat; thus condensation produces a rise of temperature (p. 47). When air resting over water is heated by the Sun's rays, evaporation begins actively and diminishes the rate of rise of temperature in the air. On the other hand, when a portion of the atmosphere containing saturated vapour is cooling down by radiation, the vapour begins to condense, giving out heat, and so retarding the rate of fall of temperature. In both cases the tendency is toward moderation and slowness of change. The cooling of air containing unsaturated vapour goes on unchecked until the temperature of saturation is reached.

Absorptive Power of Air.—The water-vapour of the atmosphere is not transparent to all light; it absorbs certain rays from sunlight, producing black lines or bands in the spectrum, particularly a set in the yellow known as the *rain-band* (π in Fig. 8). The rain-band in the spectrum increases in width and darkness as the mount of vapour in the slice of atmosphere looked through increases, and the probability of rain occurring within a certain time may be judged from the darkness of the band. The heat rays of the Sun pass readily into the atmosphere, but heat does not so readily pass out through the air into space. The atmosphere thus acts toward the Earth as a great blanket, or rather a heat-trap allowing radiant heat to enter freely but greatly retarding its escape. Water-vapour has usually been considered the chief heat-entrapping agent, because the chilling by radiation at night is always greatest when the proportion of water-vapour in the air is least. But there is now reason to believe that condensed water and solid dust-motes are more powerful in producing the effect.

Dust.—Solid dust is always present in the atmosphere throughout its whole depth. Twenty million meteorites are calculated to reach the Earth every day, and most of these are broken up by the friction of the air, furnishing a supply of *Cosmic dust* (p. 94), which being excessively fine, and even invisible, settles down very slowly. Terrestrial dust is carried into the atmosphere by ascending currents of air and is of diverse origin, resulting from the wearing down of rocks, from volcanic explosions, from flowers in the form of pollen, from minute organisms either plants or animals, from burning fuel, from factories, mines, flour-mills, and from the spray of the sea. The number of motes in the air is almost incredible. Every puff of smoke from a cigarette contains about 4000 million separate granules of dust. Dust appears to float in the atmosphere, and the motes of a sunbeam seem to be rising as often as falling. This is, however, a result of currents of air. In still air, dust always falls, but the large motes fall most rapidly under the pull of gravitation, and against the resistance of the friction of the air. When a cube of stone one inch in the side is falling, its mass drags it down, and the friction of the air on its six square inches of surface resists the fall. If the cube were cut into ten slices $\frac{1}{10}$ of an inch thick, each of these into ten bars, and each of these into ten cubes $\frac{1}{10}$ of an inch in the side, there would result 1000 little cubes drawn down by the same force as had acted on the one; but the atmosphere would now have sixty square inches of surface to act on. If each of these little cubes were cut into 1000, the downward attraction of the Earth on the whole million would be the same as for the one-inch cube, but the air-brake would be applied to no less than 600 square inches of surface, so that their fall must be very slow indeed. The average dust-motes of the air are much smaller than these, hence it is not surprising that even the stillest air is never free from dust.

Quantity of Dust in Air.—Dr. John Aitken, the discoverer of the importance of dust in Nature, invented an ingenious piece of apparatus by which he was able to count the number of invisible dust-motes in any sample of air. His numerous experiments show that in one cubic centimetre of the air of great cities there are hundreds of thousands of motes; in the air of small villages there are thousands, and there are hundreds even in the open country far from towns or factories. These minute motes catching and scattering the sunlight are the agents by which the whole atmosphere is so illuminated that not even the brightest of the stars is visible by day. If the air were free from dust we should probably see the Sun shining from a perfectly black star-filled sky, and one side of a house would be dazzlingly illuminated, the other in a shadow of absolute darkness. The blue colour of the clear sky is largely due to the scattering of sunlight by the dust-motes of the higher layers. The red tints produced at sunrise and sunset and the lingering twilight of high latitudes have a similar origin. Twilight is produced when light from the Sun, while still below the horizon, strikes on the upper atmosphere, too obliquely for refraction to bend the rays down to the surface; then the illuminated dust-motes of the upper air light up the sky for hours with a soft shimmer.

BOOKS OF REFERENCE.

R. Angus Smith, *Air and Rain.* Longmans.

Sir W. Ramsay, *The Gases of the Atmosphere.* Macmillan and Co., 1896.

See also lists at end of Chapters VIII. and IX.

CHAPTER VIII

ATMOSPHERIC PHENOMENA

Solar Energy in the Atmosphere. — All the changes in the atmosphere are directly or indirectly due to the radiant energy received from the Sun (pp. 83-87), the whole of which must pass through the air before reaching the Earth's surface. On lofty mountains, where the atmosphere contains little water-vapour and few dust-motes, the air is heated so slightly by the Sun's rays passing through, that it remains bitterly cold, although the Sun's direct heat blisters the traveller's face and hands. At an elevation of 11,000 feet, water has even been boiled by exposing it in a blackened bottle to the sunshine. On account of the low pressure of the air at great heights, air from sea-level on being caused to rise, expands greatly, as explained by Boyle's law (p. 104). The work of expansion against the attraction of gravity necessarily consumes heat, and the temperature of the expanded air, if unsaturated (p. 110), falls 1° for every 180 feet of ascent. When cold air from a great altitude is carried toward the Earth's surface by a descending current, the pressure upon it is continually increasing, and its volume is being reduced. The work thus done on the air by gravity is changed into heat, and the temperature of the air, if unsaturated, rises 1° for each 180 feet it descends. The actual rate of change of temperature in the air near the Earth's surface is not so great as this, for the Sun has a certain heating effect and the air is not always unsaturated. Observations at places on the Earth's surface at different levels have shown that the actual falling off of temperature with height is about 1° for every 270 feet of ascent, which is very nearly the rate of change of temperature in saturated air under reduction of pressure. Thus, whatever the temperature may be at sea-level, there is a certain height where the air reaches the temperature of 32° F., no matter how much sun-heat passes through; and snow which falls above that height does not melt. The limit where the temperature is always below 32° is termed the *snow-line*. It is sea-level in the extreme arctic regions, about 5000 feet at latitude 62° in Norway, about 9000 feet in latitude 46° in Switzerland, and above 16,000 feet at the equator (see figure 63 and section in Plate VIII.).

Temperature of the Upper Air.—The study of the higher reaches of the atmosphere was greatly advanced early in the twentieth century by the establishment of an international organisation for the systematic use of kites and free balloons carrying self-recording instruments. The result of this has been to show that for about six miles above the level of the sea the temperature falls uniformly, and then at a level which is higher in equatorial than in polar latitudes the temperature ceases to fall and remains the same or may even increase slightly as the height increases. The portion of the atmosphere of nearly uniform low temperature was once called the isothermal layer, but it seems better to employ M. Teisserenc de Bort's name of the *Stratosphere*. The temperature of the stratosphere varies greatly at different places and at different times, ranging from more than – 40° to less than – 80° F., but generally the temperature of the stratosphere is least over the tropics. The sudden change which occurs at the meeting-place of the lower atmosphere where animal life is possible and the upper atmosphere where it is not, is very remarkable and the progress of research points to the great importance of the region in the science of meteorology.

Heating and Cooling of Air.—Near sea-level the dense air is charged with water-vapour and dust which, during the day, absorb solar radiant energy and pass on the heat to the air. The ground also is rapidly heated, as its specific heat is only about one quarter that of water, and its temperature therefore rises four times as much as water does for the same amount of heat. Once heated, the ground is effectual in heating up the air in contact with it. In the case of water, the Sun's rays penetrate to a great depth, the temperature of the surface is very slightly raised, and transfers little heat to the air over it. Hence in sunshine a land surface heats air greatly, a sea surface heats it only slightly. After sunset the hot land radiates its heat through the atmosphere, and falls to a low temperature, thereby chilling the air in contact with it, and were it not for the dust-motes and condensed water catching and retaining most of this heat (p. 113) the radiation of a single clear night would chill down the land far more than the solar energy received during the day could heat it up. The temperature of the dust-motes is also lowered by radiation from the particles at night, and this is not fully compensated by the heat radiated from the ground, so that the air temperature falls greatly. From a water surface heat is radiated slowly at night, and the air over water is not greatly chilled.

Dew and Hoar-Frost.—On a clear night, when the temperature of the land surface falls to the point at which the water-vapour present becomes saturated, moisture is deposited on all exposed objects in the form of drops of dew or as small crystals of ice, called hoar-frost. The temperature of saturation of water-vapour is hence called the *dew-point*. The deposition of dew, or of hoar-frost, liberates heat (p. 112), and so diminishes the subsequent fall of temperature. In 1814, Dr. Wells published a number of experiments on the cause of dew. He showed that it was only deposited when the sky was clear, and on objects which had become greatly cooled by radiation, and he proved that these in turn chilled the air below the dew-point, and so condensed the water-vapour on their surfaces.

On a cloudy night radiation is checked, the water spherules of the clouds retaining and radiating back the heat lost by the Earth, so that dew is not formed. Dr. John Aitken has however shown that though the chilling by radiation of exposed objects is certainly the cause of dew, only a small part of the moisture is extracted from the air. Indeed, on a still night when there is no wind the air resting over a cabbage, for example, could never have contained the quantity of water found on the leaves in the morning. This is really condensed from the water-vapour always being breathed out by plants. On a gravelled road also, the under side of the gravel and not the upper, is often wet with dew, the stones chilled by radiation condensing the water-vapour which is always rising from the ground.

Condensation and Dust.—It is remarkable that, as far as we know, water-vapour in natural conditions never condenses except upon a solid substance. In air quite free from dust, water-vapour has been cooled far below the dew-point without condensation; but the instant a puff of common dust-laden air is admitted, each dust-mote becomes a nucleus, and a globule of water is formed upon it. All condensation of water-vapour in the air, whether it appears as rain, mist, fog, cloud, or snow, is believed to take place on a nucleus of dust.

Fog and Mist.—When dust-motes are very numerous, and the temperature of air falls suddenly below the dew-point, each mote can receive only a small coating of water. The minute globules formed in this way fall very slowly, and in the absence of wind may remain suspended in the air for a long time. This accounts for the black winter fogs of great cities where the specks of soot are very numerous and are only thinly coated with water. Over the open sea, when a broad stream of warm air carrying saturated water-vapour crosses a cold current of water or meets an iceberg, the sudden cooling of the vapour necessitates an enormous condensation, and the dust which is abundant even far from land, enables the condensation to take place in the form of a bank of mist. The famous "fogs" of Newfoundland are so produced. Fog differs from mist in not wetting solid objects with which it comes in contact. The light mists formed at night over low-lying meadows or valleys are usually very thin sheets, and as soon as the Sun appears the water particles are heated up and evaporated again, so that the mist clears quickly away. When a mass of warm air rises in the atmosphere its temperature falls (p. 116), and on reaching a certain height the vapour becomes saturated, and as it still rises, and the temperature continues to fall, the vapour condenses upon the dust-motes forming a mist. *Clouds*, which are mists at high altitudes, often hang over a mountain or sail slowly through the air for hours. In such a case, though the form of the cloud may not change, the water globules composing it are always falling as fast as the friction of the air allows (p. 114), and when they reach the warmer air below they are evaporated again and vanish while new globules are as rapidly condensed in the stratum above.

Classes of Clouds.—The differences between clouds arise mainly from the height of the layer of mist composing them. Three types of cloud are distinguished by characteristic forms and by their usual elevation, and all other kinds may be classed as a mixture of two or more of them. The highest form of cloud is a mist of minute ice-specks, usually forming at a height of about 5½ miles above sea-level. It appears like tufts or curls of snow-white hair, and is named *Cirrus*. In certain conditions this cloud gives rise to halos, wide faintly-coloured rings which appear to surround the Sun or Moon. The name *Mare's tail* is sometimes applied to it. Little rounded tufts which often cover the whole sky in summer and are familiarly called *mackerel scales* belong to a class of cloud which floats about 3 miles above the Earth's surface, and may be looked upon as half-way between cirrus and the next type ; it is termed cirro-cumulus. *Cumulus* is the cloud type which comprises the great white billowy clouds common in summer. They are usually flat on their under surface, and rise above into rounded forms often of wonderful beauty. The base of cumulus cloud is usually about ¾ of a mile above the Earth's surface, while the summits may rise as high as 2 or 3 miles. These clouds are formed by the condensation of vapour in ascending currents of air, and each mass of cumulus has been likened to a grandly carved capital topping the invisible column of rising heated air. The lowest clouds are sheets of mist floating within half a mile of the Earth's surface, and being so low they are usually seen edgeways when at any distance, and so appear as long layers parallel to the horizon. This arrangement gave rise to their name of *Stratus*. A cloud, presenting a dark grey or black colour and a ragged stormy appearance, from which rain usually falls is called *Nimbus*, or simply rain-cloud. It forms at the elevation of about a mile, and is described as a mixture of cumulus and stratus. The upper clouds act as floats, the study of which was the only guide to the movements of the upper atmosphere before the introduction of sounding balloons and meteorological kites. The lower clouds are of great value as heat curtains, preventing the Sun's heat from being excessive by day, and almost entirely checking the loss of heat by radiation from the Earth at night.

Rain.—Sometimes the temperature of air remarkably free from dust falls below the dew-point, and a large quantity of water-vapour must condense, while there are very few solid motes to act as nuclei. Each mote consequently gets a very heavy coating of water, and drops are formed which are too large to be much checked by friction of the air as they fall. Thus a shower of rain may fall from a cloudless sky. Rain more often originates in clouds. The upper part of a very deep layer of cloud is less dust-laden than the lower ; the motes accordingly gather larger water-drops, and these descend comparatively quickly, overtaking and embodying smaller globules as they fall, until they emerge from the cloud as large drops of water. If the cloud floats very high above warm air, the vapour of which is unsaturated, the raindrops will evaporate as they fall and may vanish before reaching the Earth. But if the cloud is low or the vapour in the air traversed by the rain-drops is nearly or quite saturated, there is so little evaporation that they reach the surface undiminished or even increased in size. When much water-vapour is rapidly condensed near the surface or over air which is fully charged with vapour, there must be a great fall of rain. Hence, when a warm vapour-laden sea-wind blows horizontally against the side of a mountain, the air is forced upward along the slope, and growing cold in consequence (p. 116), the dew-point is reached and passed, and deluges of rain fall, while dark masses of clouds fill the sky. On the other hand, when wind blows over a mountain range and descends on the other side, it grows warmer as it sinks, evaporates all the cloud it carries, and becomes a drying wind upon the low ground. When air is rising from any cause, as for instance in the ascending whirl of a tornado, or by the insertion beneath it of a body of denser air, precipitation of vapour as rain must take place when the ascending air reaches the saturation point, and as a cyclone sweeps over the country deluges of rain may fall on low plains or on mountains. Rainfall is measured by the rain gauge, and its amount is stated in the number of inches of water which would accumulate on a level surface if the rain were to rest where it fell.

Snow is produced when water-vapour condenses at a temperature below the freezing-point, although in certain circumstances not yet fully understood liquid water drops may exist at very low temperatures. The freezing water forms small clear spicules of ice which always meet at an angle of 60°, so that snow-crystals usually have six rays uniformly arranged about a centre; but the variety and beauty of the forms is very great. A number of crystals getting hooked or felted together forms a snow-flake, and the fluttering showers of flakes rest lightly on the ground, sometimes covering it to the depth of several feet. One foot of snow is, roughly speaking, equivalent to one inch of rain. The whiteness of snow is produced by the reflection and refraction of light again and again amongst the numerous small crystals. The real colour is bluish or greenish like a block of ice. A great quantity of air is entangled between the spicules of snowflakes, and this makes a covering of snow act as a non-conductor of heat—almost as perfectly as a covering of feathers—preventing radiation from the Earth at night, and so keeping the ground from freezing in cold weather. Under heavy pressure snow is compacted into solid ice.

Hail.—In winter there are often showers of tightly packed little snowballs about the size of small shot or rarely as large as peas. This is called soft hail, and it appears to be formed by the larger ice particles in a deep ice cloud overtaking and adhering to the smaller ones. True hail is a different thing, which only occurs in warm weather usually as an accompaniment of summer thunderstorms or tornadoes. True hailstones are irregular lumps of ice which sometimes weigh several ounces, and occasionally several pounds. A shower of such masses is very destructive, breaking windows, cutting down standing crops, and often killing animals or even people. The hailstone when cut across usually shows alternate layers of clear ice and of compact snow. According to Ferrel such a hailstone is produced by an ordinary soft hailstone formed at a great height falling into a rain-cloud, where it gets a coating of water, and then being carried by an ascending current into a high cold region, where the water is frozen into clear ice and a deposit of snow takes place outside. The same hailstones may be caught in ascending and descending currents several times in succession, thus getting alternate coats of ice and snow. This theory accounts for true hailstones only occurring in summer, for it is only in hot weather that sufficiently powerful ascending currents of air are formed.

Electrification of the Atmosphere. — Every change in the atmosphere, particularly evaporation, condensation and wind, gives rise to some disturbance in the distribution of electricity. As an electric charge resides on the surface of a body, it follows that when the minute particles of a cloud are uniting to form raindrops, their electrical potential (p. 49) is rapidly rising, because the surface of a large rain-drop is smaller than the total surfaces of the small water globules which combine to form it. A heavy shower of rain rapidly carries off the electricity, reducing the potential of a cloud to that of the Earth. In certain states of the atmosphere which are not yet thoroughly understood, silent electric discharge takes place between pointed bodies, such as flagstaffs or the masts of ships, and the air. This is accompanied by a pale brush-shaped light, which goes by the name of *St. Elmo's fire.* Air which is almost free from water-vapour is a nearly perfect non-conductor (p. 49), and in the dry climates of mountain observatories and high latitudes in winter, electricity produced by friction is not immediately conducted away to the Earth as it is in damp air. In Canada one can often light a gas-jet by an electric spark from the finger, produced by shuffling the feet on the carpet; and at Pike's Peak observatory in the United States the friction of opening a drawer or shutting a door often gave rise to electricity enough to give a severe shock.

Lightning and Thunder. — When the electric potential of a cloud becomes much higher than that of the Earth or another cloud, a disruptive discharge takes place between them through the air (p. 50). The electrical energy is mainly converted into heat by the resistance of the air, the particles of which become instantaneously white hot; but the passage of the electric current is so rapid that only a brilliant flash is visible. The intensely heated air expands suddenly, and then as suddenly contracts, setting up a succession *of air-waves (p. 37) all along the line of the* flash. These reach the ear as a prolonged growl or roar, or as a sharp rattling explosion, according to the distance of the observer and to the direction of the flash. The sound is prolonged by echoes from the Earth's surface and hills, or from clouds. The electric discharge follows the path of least resistance, and as vegetable juices offer less resistance to it than air, trees are often traversed by the current. The sap between the wood and the bark is so heated by the discharge that steam is formed with explosive violence, splitting off the bark, tearing away branches, and ploughing deep furrows in the solid wood, as if the tree had been struck by a solid spear hurled with gigantic strength. An animal or a human body may form part of the path of least resistance and so be "struck," but this will never happen if there is a better conductor near. The impressiveness of a thunderstorm is largely due to the majestic roar of the thunder, the darkness of the sky, the lurid glare of the clouds, and the ominous stillness of the air; but apart from these the presence of highly electrified bodies produces an indescribable effect on the nerves of many people. Lightning-conductors attached to buildings serve to equalise the potential of the Earth and clouds, and thus tend to prevent a disruptive discharge from taking place. A thunderstorm, or the squall producing it, is usually accompanied by torrential rain or hail, concentrated on a small area of country, and sometimes occurring in a series of consecutive patches often arranged in parallel lines. As much rain may fall in an hour during a thunderstorm as is produced in twenty-four hours during the passage of a cyclone, or in a whole month of average rainfall. Thunderstorms occur most frequently in the tropics, and usually during the day; in polar regions they occur very rarely, and then only at night.

The Aurora.—In the north polar regions, where thunderstorms are practically unknown, beautiful luminous effects are produced at night by the *Aurora borealis* or Northern Lights (see small map on Plate XIV.). A similar appearance in the south polar regions is called *Aurora australis.* The Aurora forms an arch or ring of coloured light over the magnetic pole (p. 65) at a great height in the atmosphere, from 50 to 150 miles. Coloured fringes and streamers shoot from this arch in all directions, sometimes spreading over the whole sky, and again shrinking back with a pulsing motion. The Aurora appears to be caused by electrical discharges in rare air, as it very closely resembles the glow seen when a current traverses a "vacuum tube" containing a little highly rarefied air. This theory was confirmed by the Finnish physicist Prof. Lemström, who covered the top of Mount Oratunturi in the north of Finland with a network of wires and found a true Aurora produced when he sent a current of electricity from these wires to the Earth.

Wind.—The normal condition of air seems to be one of motion, and air in motion is called wind. In air at rest wind may be set up by unequal heating. Thus, when air is heated at the Earth's surface it expands, and becoming less dense, rises and flows away in the upper regions of the atmosphere. The pressure of the air over the region where expansion has taken place thus becomes less than that of the surrounding atmosphere, and air is accordingly driven in from all sides until equilibrium of pressure is restored. Wind always blows from regions where the pressure is higher to those where it is lower. The greater the difference of pressure, or rather the *gradient*, that is difference of pressure in a definite distance, the stronger is the wind. In English-speaking countries gradient is measured by the number of hundredths of an inch difference in the reading of two barometers at a distance of 15 nautical miles (17 miles). For example, if the barometer at one place read 29·14, and at another 34 miles away it read 29·00, the difference is 14 hundredths of an inch in 34 miles, or 7 in 17, and the gradient is spoken of as 7. The same gradient would result from a barometric difference of only 3·5 hundredths of an inch if the stations were only 8½ miles apart. The strength of wind is proportional to the gradient as the following table shows:—

Gradient - -	0·5	3	7	15
Velocity of wind in miles per hour	7	25	50	80
Wind - - -	Light breeze.	Fresh breeze.	Gale.	Hurricane.

Wind ceases to blow as soon as the difference of pressure ceases to exist. While blowing, currents of air move spirally from areas of high pressure to areas of low pressure, deviating toward the right hand in the northern hemisphere and toward the left hand in the southern (p. 58). The strength of wind is measured by anemometers, and is expressed either in terms of its velocity or of the pressure it exerts. Wind is named by the direction from which it blows, a wind blowing from east to west being called an East wind.

Circulation of the Atmosphere.—In order to understand the movements of the atmosphere as a whole, it is convenient first to consider the Earth as smooth and entirely surrounded by the hydrosphere. The air between the tropics, and especially over the equator, is always being heated by strong solar radiation, and it consequently expands and rises, through the rest of the air, as oil would rise through water. This region forms the furnace which furnishes motive power for the whole system of circulation. The cooler and denser air from the neighbouring temperate zones flows toward the equator along the surface to take the place of the ascending air, and is in turn heated and forced to rise. The polar regions receive little heat from the Sun at any time, and in the long dark winters radiate heat away into space. The air over them consequently becomes chilled, grows denser, and descends toward the surface. Thus by equatorial heating and polar cooling the air is constantly being raised at the equator, carried in the upper regions north and south toward the poles, brought down to the surface and drawn back toward the equator. The upper current blows spirally as a wind from the west-south-west in the northern hemisphere, and from the west-north-west in the southern hemisphere according to the law of deviation, while the winds from the poles would blow from north-east in the northern hemisphere and from south-east in the southern.

Theory of Circulation.—George Hadley in 1735 and Professor J. Thomson in 1857 showed as the result of this arrangement that in the upper layers of the atmosphere the pressure is highest above the equator and lowest over the poles. But the rush of air at a lower level from the poles towards the equator tends to carry the mass of the atmosphere in that direction,

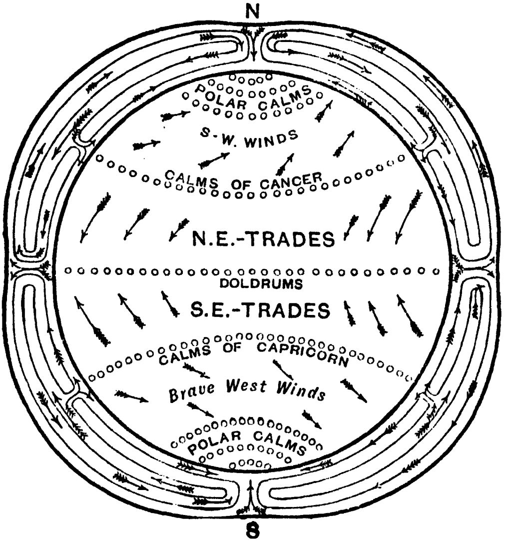

FIG. 22.—Theoretical Circulation of the Atmosphere, after Ferrel. The arrows show the directions of the wind over the surface and of the vertical movements of air. (This diagram is the same as J. Thomson's.)

while the movement of the upper air toward the poles tends to carry the mass of the atmosphere in the opposite direction. The two tendencies balance each other between latitudes 20° and 30° north and south, and the pressure of the lower strata of the atmosphere is thus greatly increased in the neighbourhood of the tropics. This is shown in Fig. 22 by the boundary line of the portion of the atmosphere shown being drawn nearest the surface at the equator and poles, farthest from it at the tropics. The arrangement of pressure at the surface is thus—Two belts of air at high pressure girdle the Earth a little poleward of the northern and southern tropics, a ring of air at lower pressure lies along the equator, and great regions where the atmospheric pressure is low surround the north pole and the south pole. The tropical zones of high pressure give rise to surface winds toward the equator, strengthening the north-east and south-east winds of the lower atmosphere. They also produce air currents toward the poles in the opposite direction as south-west and north-west winds, which gradually die away about the polar circles, where the equator-seeking winds meet, check, and rise above them. Hence in the temperate zones the surface winds should be parallel to the pole-seeking upper winds, while between the two are the equator-seeking middle winds. In the tropics and the polar regions there are only the lower equator-seeking winds and the upper polar-seeking winds, as shown in the diagram.

This theory is not sufficient to explain all the phenomena that have been observed, especially in the polar regions; but it may serve the purpose of presenting a rough picture of the general circulation until the investigation of the free atmosphere has been carried out systematically in the tropics and the polar regions, and fuller information secured.

Zones of Winds and Calms.—This theoretical circulation divides the Earth's surface into zones, which roughly correspond to those of solar climate (p. 86). In the tropical belts of high pressure, from which surface winds blow poleward and equatorward, there are calms. Since the upper air, which contains little vapour, is always descending, these regions are cloudless and the scene of enormous evaporation. The temperate zones of poleward surface winds receive the hot vapour-laden tropical air and conduct it to colder regions, where much of its vapour is condensed. They are thus windy cool regions of moderate cloudiness and rainfall. In the polar regions of low pressure, where it is assumed that most of the air descends from above, the wind is relatively dry. The tropical regions swept by the equator-seeking airflow are windy, hot, with little cloud, and the scene of great evaporation from the warm sea surface. The narrow equatorial belt of low pressure into which the equator-seeking winds blow from north and south is also a region of calm. The air as it ascends here expands, cools, and the enormous supply of vapour swept in from the tropics condenses into the heaviest cloud, and falls as deluges of rarely ceasing rain. The heat liberated by the condensation of so much vapour strengthens the equatorial up-draught. The equatorial belt of low pressure always lies nearly under the vertical Sun, consequently in the northern summer it swings to the north, and in the southern summer it swings to the south, displacing the belts of tropical high pressure northward and southward alternately. For reasons which cannot be explained here, this displacement is comparatively slight, extending over only five or six degrees of latitude. In the North Atlantic, for example, the equatorial low pressure belt never moves farther south than 5° N. All parts of the Earth's surface that the equatorial rain-belt traverses in its annual movement experience a rainy season as it lies over them, and a dry season all the rest of the year, when swept by the equator-seeking winds. Near the equator, where the narrow rain-belt crosses a tract of the Earth both in its northward and in its southward swing, there are two wet and two dry seasons in the year. The theoretical circulation of the air and the resulting climates are affected by two causes, unequal heating of the air by land and sea surfaces (p. 135), and the deflection of the prevailing winds by plateau edges and mountain ranges. Regular zones of surface winds and climates consequently are found only in great expanses of ocean, and do not appear in narrow seas or on land (see Plates V., VI., VII.).

Trade Winds and Doldrums.—The Elizabethan voyagers spoke of those winds which blew steadily in one direction all the year round as "blowing trade," the word *trade* meaning no more than that they pursued one track, treading the same path. The name has since been extended to include all the permanent winds which blow from the tropical toward the equatorial calms; and these have been found to be remarkably constant in force as well as in direction, blowing always a fresh breeze, never falling to a calm and never rising to a gale, but keeping the blue waves for ever sparkling with caps of foam. In the winter half of the year (November to April) the north-east trades of the Atlantic are felt as far north as 25° N. and reach southward to 5° N.; and in the Pacific they sweep over the range of sea between 28° N. and 8° N., and the tropical calms reach as far north as 40°. The south-east trade winds at the same season are experienced in the Atlantic between a line drawn from the Cape of Good Hope to Rio de Janeiro, and the equator. In the eastern Pacific they reach farther north, crossing the equator to at least 5° N. The equatorial belt of calms and rains lies entirely to the north of the equator; its width varies from 120 to 200 miles in the Atlantic, and is about 300 miles in the Pacific. This calm belt, called by sailors the *Doldrums*, was greatly dreaded in the days of sailing ships, on account of the absence of wind, which often kept a vessel rolling helplessly for days, or even weeks, while the close damp air made the men dispirited and ill. Thunderstorms of terrific violence are very common in it. It was consequently of the greatest importance for a captain to know where the narrowest part of the belt could be found at each season, in order that he might pass quickly from the clear bright skies and fresh invigorating winds of the north-east trades to the equally pleasant and favourable region of the south-east trades. During the summer half-year (May to October) the rain-belt of the Doldrums with its calms moves farther north, and widens to from 300 to 500 miles. The north-east trades then begin in about 30° N. and die off about 12° N., while the south-east trades do not extend so far south, but cross the equator, blowing as far as 5° or even 8° N. (Plate VII.)

The Roaring Forties is a name given by sailors to the belt of ocean between 40° and 50° S. in which the "Brave West Winds" blow all the year round, as regularly as the trades and more strongly, often rising to gale force. This belt is more nearly covered with a uniform stretch of ocean than any other part of the Earth, and exhibits something very like the theoretical circulation of the atmosphere. The prevailing wind is produced by the high pressure of the south tropical calm belt and the remarkably low pressure which surrounds the Antarctic Circle, to the south of which the prevailing wind has an easterly component. The strength and constancy of the brave west winds long enabled sailing vessels to compete with steamers in trading with New Zealand going by the Cape of Good Hope and returning by Cape Horn.

The Northern Westerlies.—The south-west winds of the northern hemisphere, which blow from the northward edge of the north tropical zone of high pressure toward the north polar region of low pressure, are sometimes called the Antitrades; but they are much less constant and more variable in strength than the trade winds or the winds of the Roaring Forties. The trade winds blowing into the Gulf of Mexico in the summer months from the east or south-east are deflected by the edge of the great table-land of Mexico into south-westerly winds, which blow up the Mississippi valley and sweep across the Atlantic, reinforcing the somewhat uncertain westerlies.

While there is no doubt that changes of pressure produce winds, it must be remembered also that winds may produce differences of pressure, and it is not always possible to say which of the two associated conditions is the cause and which the effect.

Daily Temperature Changes.—The circulation of the atmosphere which has just been described was deduced by mathematical reasoning from a few simple data, and then proved by observation to be generally correct subject to disturbing causes. But the changes in the atmosphere which take place from hour to hour throughout the day were first observed in thousands of cases, and their cause has been subsequently ascertained by inductive reasoning (p. 10). Solar radiation goes on from sunrise to sunset, but the temperature of the air reaches its maximum about 2 P.M. local time, or about 2 hours after the Sun has passed the meridian. Cooling then sets in, and the temperature reaches a minimum about 5 A.M., or shortly before sunrise. These hours apply to the tropics and vary slightly in different parts of the world, but the air is generally coldest in the early morning and warmest in the early afternoon. Sir David Brewster discovered, by comparing a long series of hourly observations, that the average temperature at any pair of hours of the same name (*e.g.* 9 A.M. and 9 P.M.) was very nearly the average temperature for the whole day, and it has since been recognised that if the temperatures at 9 A.M., 9 P.M., the maximum for the 24 hours, and the minimum are added together and divided by 4 the diurnal mean is still more nearly approached. Fig. 23 shows the range of temperature above and below the average for the day, the hours being marked along the top and the temperature in degrees above and below the average on the side. The heavy curve refers to a station in the tropics, the lighter curve to a temperate region.

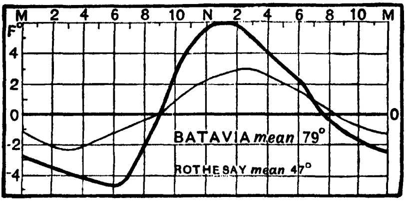

FIG. 23.—Daily Range of Atmospheric Temperature in Temperate and Tropical Climates. (After A. Buchan.)

Daily Pressure Changes.—The pressure of the atmosphere is least about 4 A.M. and 4 P.M. and greatest about 10 A.M. and 10 P.M. In Fig. 24 the diurnal range of the barometer above and below its mean value is given, the range in fractions of an inch being marked on the side, the hours from midnight to midnight along the top. The heavy curve shows the typical range in the tropics, the lighter curve that in a temperate region. This regular increase and decrease of pressure twice daily was for a long time supposed to be a tidal effect caused by the differential attraction of the Sun; but if it were tidal the Moon would exercise a greater influence than the Sun, and this is certainly not the case. The phenomenon cannot therefore be produced by gravitation, and we are thrown back on solar radiation as the only other

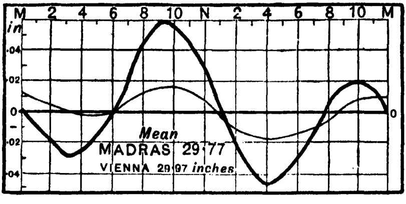

FIG. 24.—Daily Range of Atmospheric Pressure in Temperate and Tropical Climates. (After A. Buchan.)

sufficient cause. It is very difficult to see how the diurnal heat wave with its one maximum and minimum could be transformed into a double pressure wave, which seems to be the only uniform semidiurnal recurrence in Nature. The amplitude of the semidiurnal pressure wave is greatest at the equator and diminishes towards the poles. In the temperate zones it is rarely seen, being lost in the great irregular pressure changes of cyclones and anticyclones; but between the tropics the regular double swing is a prominent feature in the barograph curve every day in the year. Dr. Buchan attempted to account for the phenomenon by the condensation and evaporation of water on dust-motes leading to the morning minimum and maximum, and to the removal of heated air bodily eastward and the inflow of cooler air behind it for the afternoon minimum and maximum. But this assumes a resistance to instantaneous change of pressure in the atmosphere which has been shown not to exist, and the problem of the regular diurnal variation of the barometer has not yet been solved.

Land and Sea Breezes.—The different heating and cooling of land and sea produces a regular change in the daily winds of tropical coasts and islands, and in very calm clear weather similar effects may be observed in all latitudes. An island or strip of coast when heated by the Sun gives rise to ascending currents of air (Fig. 25). About 10 A.M. these ascending currents, having carried the air into the upper regions, produce a fall of pressure over the land compared with that over the cooler sea, and a sea-breeze sets in, at first as a very gentle air, but gradually increasing in force until about 3 P.M., when the land surface is most highly heated. After that hour the land cools down more quickly than the sea, and as the atmospheric pressure becomes equalised the sea-breeze dies away. The air over the land continues to cool down and to sink; more air consequently flows in above, and the pressure over the land thus becomes greater than that over the sea. A surface land-breeze (Fig. 26) sets in about 8 P.M., often with sudden squalls, which are dangerous to boats. It gradually increases in strength as the land grows cooler until it reaches a maximum about 3 A.M. In the trade-wind regions the land and sea-breezes are often not strong enough to reverse the direction of the prevailing winds, and merely alter the strength, On the south-east coasts of the Fiji Islands, for example, the prevailing south-east trade wind is intensified during the day and much reduced at night, while on the north-west coasts the wind is reduced through the day and strengthened at night. Land and sea-breezes are always light on a low flat island or coast; but when a range of mountains rises near the sea very strong winds are produced, the mountain slope acting like a flue, aiding the ascent of the hot air by day and the descent of cold air by night. On account of the lofty backbone of the Blue Mountains the sea-breeze in Jamaica is the strongest known.

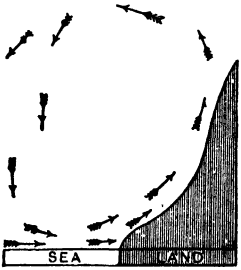

FIG. 25.—Sea-Breeze during Sunshine.

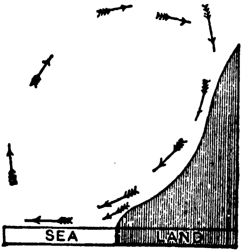

FIG. 26.—Land-Breeze at Night.

Monsoons.—Over the centre of continents far removed from the ocean the range of air-temperature is greatest, the great dryness of the air favouring radiation and producing very high temperatures in summer and very low temperatures in winter. Over the sea the range of temperature is least. The continents, by heating the air in summer, set up ascending currents which last for months, so that the pressure of the air is greatly lowered, and surface winds blow in toward the continent from the surrounding seas. In winter, the air being cooled by the continents produces descending currents; the pressure becomes much higher than that over the less chilled seas, and consequently surface winds blow outward from the continents during the winter months. These winds changing with the seasons are called Monsoons. They are produced exactly like land and sea-breezes, only with a period of a year instead of a day. Just as in the former case, monsoon winds may be too feeble to reverse the direction of the prevailing winds, and may succeed only in modifying their force (see Plate VII.). The monsoon effect of most continents is comparatively insignificant, and is confined to a small part of the coast. In the southern continents these winds are slightly developed, because in the widest part of South America and Central Africa the annual range of temperature is very small, and in the narrower part farther south the influence of the vast expanses of the neighbouring oceans predominates all the year round. In Australia the monsoons are well-marked but not very strong, although the range of temperature is considerable; but with an equally great range the Sahara region of North Africa has a very much slighter monsoon-raising power. The flatness of that expanse of land and its slight elevation partly account for this; the disturbing influence on atmospheric pressure of the expanses of sea to the north is also important. On the west coast of North America there are distinct monsoons, but it is in Asia, with its steep mountain slopes rising from the sea or from low plains, that the monsoon blows with greatest power, and in India the name was first applied.

Fohn Winds.—In mountain valleys and on the leeward side of mountain ranges a warm dry wind often blows with great force. It is called the Föhn in the Eastern Alps. It melts the snow on the mountains, producing avalanches, and it dries all woodwork to such an extent that in Switzerland special precautions against fire are enforced in the season when the Föhn is most frequent. The Chinook wind of the Great Plains of Canada is of this kind, and blowing warm from the west it melts the winter snow and raises the average temperature of the plains. It seems to owe its warmth to the thermodynamic heating (p. 116) of air which has blown over a mountain range and precipitated most of its water vapour.

Similar winds have been experienced in the polar regions, where no other explanation of a rapid rise of temperature than thermo-dynamic heating of descending air is possible.

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CHAPTER IX

CLIMATES OF THE WORLD

Configuration and Climate.—In passing from the theoretical system of atmospheric circulation sketched in the last chapter to the actual conditions of the atmosphere in different parts of the world, the disturbing influence of the land must be taken into account. The student should therefore read Chapter XVI. as far as that refers to the configuration of the continents, and study Plate XI., as well as the maps illustrating atmospheric conditions. Surface winds are altered in their direction in a very marked way by mountain ranges and the edges of plateaux. At the same time, sloping land differs from level ground by setting up a local vertical circulation, acting exactly as a chimney does in increasing a draught. In hot climates mountaineers find a strong wind sweeping up the slope by day helping their ascent, and on the summit the ascending air-current from opposite sides rises straight up, and is often strong enough to carry off hats and notebooks. At night the effect is reversed, and strong winds blow down the slopes. The same effects are produced in a more intense degree in narrow steep mountain valleys, the furious day and night winds of which make travelling difficult and dangerous in some of the Himalayan passes. Experienced hunters on the Rocky Mountains build their fires just below their tent, knowing that the night-wind will carry the smoke down the valley. In still winter weather the air, chilled as a thin layer on mountain sides, grows dense as its temperature falls, and flows gently down into the valleys, filling them to a certain level with intensely cold air. The peasants in many valleys of the Alps perch their wooden cottages on knolls or rocks, not so much for the picturesqueness of the sight, but in order to stand above the surface of the flood of icy air which streams through the valley in winter. Rainfall is still more intimately connected with configuration. Meteorologists, in speaking of the *climate* of a place, mean the average state of the atmosphere with regard to warmth, wind, rain, and all other variable conditions.

Atmospheric Temperature in Different Latitudes.—The excess of land in the northern hemisphere, compared with the southern, alters the distribution of the solar energy shed equally on both, and prevents the simple astronomical climate zones (p. 87) from corresponding on the two sides of the equator. Fig. 27 shows by means of curves the mean temperature of the year, as calculated by Professor Ferrel for each 10° of latitude from 80° N. to 60° S. Latitude is marked along the top and tempera-

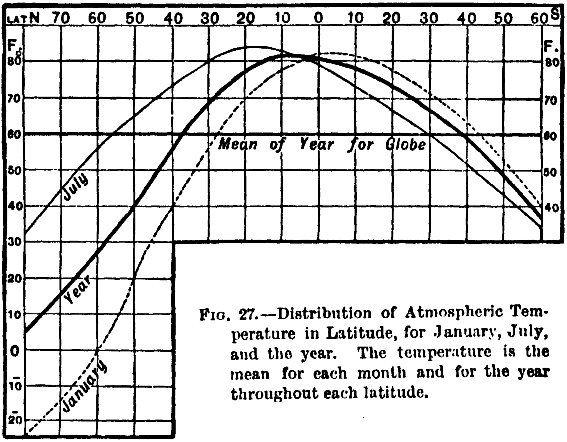

FIG. 27.—Distribution of Atmospheric Temperature in Latitude, for January, July, and the year. The temperature is the mean for each month and for the year throughout each latitude.

ture up the side of the diagram, the three curves of which correspond to the average temperatures of January, July, and of the whole year. The curve of average temperature for the year shows that the warmth of the air at 80° N. is only 5° F., that in 4° N. there is the highest temperature of 81° F., and that in 60° S. it is 35° F., the northern hemisphere being as a whole a little colder than the southern. Later information suggests a somewhat lower July temperature for 60° S.; but as far as 50° S. latitude the diagram is substantially correct. The mean surface air temperature of the whole Earth is about 59·5°. The curves for January and July show a great annual range of temperature in the northern hemisphere, increasing toward the north where the land preponderates, and a slighter annual range in the southern hemisphere, decreasing toward the south where the sea influence prevails.

Isotherms. — If the temperature (corrected for height above sea level) of every place in the world at some one instant, or the mean temperature for any one period, were marked in figures on a large map the result would be very confusing to look at. But if all the figures except those showing a difference of 10 degrees were blotted out the map would be much simpler. Near the equator the number 80 would occur frequently, farther north and south there would be rows of 70, still farther strings of 60, and so on. A line might be drawn through all figures 80, and the figures themselves might then be blotted out, except one left to mark the line, and the same might be done for 70, 60, and the rest, greatly simplifying the map. Such lines are termed isotherms, or lines of equal warmth, as they pass through all the places where the air temperature is of the degree named. In constructing such maps the line of 80 would be drawn midway between an 82 and 78, or between an 85 and 75, and so on. In interpreting the maps (Plates III. and IV.) it is usually assumed that the temperature between two isotherms is proportional to the distance. For example, in the January map (Plate III.) the line of 70° temperature in Central America is 1·5 inch from the line of 80° in South America, so that between them one-seventh of an inch on the map corresponds to a change of 1° of temperature. The lines of 40° and 50° in North America approach at one place on the same map to within one-tenth of an inch of each other, so that between them one-hundredth of an inch corresponds to a change of 1°. The space between the isotherms is coloured to bring out the difference of temperature, the hottest regions being shown in deepest red, the coldest in deepest blue. Isotherms are constructed to refer to sea-level, so in order to find from the maps the actual temperature at any place a deduction of 1° for every 270 (or for convenience say 300) feet must be made (p. 117). For every place on the contour-line of 600 feet of elevation 2° must be deducted, and for every point on the 6,000-foot contour-line 20° must be deducted from the isothermal temperatures. Those two contour lines are marked on the maps as a rough guide to the interpretation of the results.

Average Air Temperature in January.—January is the midsummer of the southern hemisphere. The map (Plate III.) shows that the region with a mean temperature over 70° lies to the south of the Tropic of Cancer on land, and the only areas warmer than 90° are crossed by the Tropic of Capricorn in Africa and Australia, the land being more heated than the water by the nearly vertical Sun. The eastern sides of the southern continents are warmer than the western; thus on the Tropic of Capricorn, the east coasts of Africa and South America have a temperature of 80°, and the west coasts less than 70°. This is explained by the prevailing winds and ocean currents (p. 197). The isotherm of 32° in the southern hemisphere occurs about 64° S., and its direction is nearly east and west, but is north of 60° S. south of Africa. Farther north, the direction of the isotherms becomes more irregular on account of the increasing interference of land in altering the temperature of the air. In the northern hemisphere, where January is midwinter, the air over the sea as a rule is warmer than that over the land in the same latitude, and the coldest regions are near the centres of the great continents. The coldest place where observations have ever been made is the East Siberian village of Verkhoyansk just within the Arctic Circle (Fig. 28). On account of the Arctic Sea being frozen across in winter, the marine influence to the north practically ceases during that season. The mean January temperature at this station is 61° below zero, F.; and the absolutely lowest temperature ever experienced by human beings occurred there, the lowest minimum in February having been – 93·6° F. The powerful influence of the warm surface-water of the Gulf Stream Drift (p. 198) on the air is shown by the temperature of the Lofoten Islands, in the same latitude as Verkhoyansk, being above 32° F., the difference between the two being more than 93° F. The coldest points in the American continent and in Greenland have a temperature a little under – 40°. In order to appreciate the effect of land and sea in modifying climate the student should carefully follow the isotherms of 30° and 40°, noting carefully the latitude at which these temperatures prevail near the coast and in the heart of continents. To make this exercise still more instructive, the contour-lines of 600 and 6000 feet should be noted, and the actual surface temperatures calculated.

Average Air Temperature in July.—The lapse of six months brings round the northern summer and southern winter. The Sun now vertical near the Tropic of Cancer beats down upon a far greater breadth of land surface than in January, and so the large areas with a temperature exceeding 90° in North Africa and Western Asia extend far to the northward of the tropic. The sea now exercises a cooling influence on the air of the middle latitudes in the northern hemisphere. The isotherm of 70° F., for example, runs far to the north over the continents, reaching 55° N. in North America, and also in Eastern Asia, but it scarcely gets north of 40° N. in the Atlantic, and is carried south to 25° N. in the Eastern Pacific. In higher north latitudes the slight north-eastward trend of the isotherms shows that some warming effect is still due to the south-west winds and currents. In July the Lofoten Islands, having warmed up only by 20° on account of the sluggish heat transactions of water, are at the same temperature, 55° F., as Verkhoyansk, where, however, the air has been heated no less than 116° since January, this being the greatest annual range known. The purely continental character of Verkhoyansk is modified by the fact that in summer it is not far from the shore of the cold Arctic Sea, whence cool monsoon winds blow. In the southern hemisphere the temperature of the land has fallen by radiation a little below that of the sea; but the prevailing winds are so powerful, and the oceanic influence predominates so greatly, that temperatures below 70° are found north of 20° S. on the west sides of S. America and Africa. These coasts are cooled by the increasing upwelling of ocean water due to the trade winds. The extreme tip of South America is the only southern continental land which has a winter temperature below 40° in July, and the isotherm of 32° encircles the globe between 50° and 58° S., not touching land, and showing but a slight displacement from its winter position.

Land and Sea Climates.—The comparatively cool summers and mild winters of the extremities of the southern continents compared with those of the same latitudes in the northern hemisphere are direct results of the arrangement of land and sea on the globe. A land climate always tends to be extreme, a sea climate to be mild; but an examination of Fig. 27 will show that the average temperature for the year is nearly the same in both hemispheres. Fig. 28 shows the annual range of temperature in degrees above and below the mean for the year in typical continental and oceanic climates. The solid curve shows the range at Verkhoyansk, the finer line that at the Lofoten Islands. In continental or land climates the range of temperature is great and the rainfall very small, in oceanic or sea climates the range of temperature is small and the rainfall great. Prevailing winds carry an oceanic climate for a considerable distance inland on the western coasts of the northern continents, and they carry a continental climate a considerable distance seaward on the western shores of northern oceans. The student should verify these statements by making a detailed comparison of the two isothermal maps, and the map of rainfall (Plate VIII.).

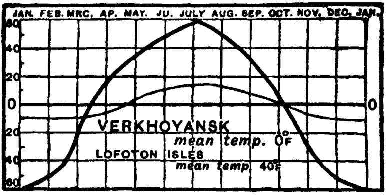

FIG. 28.—Curve of monthly mean temperature for a typical land-climate (dark) and sea-climate (light). The dark horizontal line marked 0 represents mean annual temperature; the figures show number of degrees above and below the mean.

Isobars and Average Winds. — The invisible differences of atmospheric pressure may be laid down on a map in the same way as the invisible differences of temperature. Lines running through places over which the atmospheric pressure, as measured by the barometer and reduced to sea-level, is the same, are called isobaric lines, or shortly *isobars.* Those shown on the maps (Plates V. and VI.) express the pressure in inches of mercury at intervals of every tenth of an inch, and the spaces between them are coloured, so that the regions of highest pressure are deep red, and those of lowest pressure deep blue. When adjacent isobars are drawn far apart on the map the barometric gradient (p. 126) between them is slight, and the wind set up is consequently gentle; but when the isobars are crowded closely together, a steep gradient is indicated, giving rise to strong wind. A gradient of 0·5 corresponds to a difference of pressure of 0·02 inches in one degree of latitude; a gradient of 15, giving rise to a hurricane, corresponds to a difference of pressure equal to 0·60 inches in one degree of latitude. In the maps the arrows are represented as flying with the wind. The shortest path from a region of high to one of low pressure is at right angles to the isobars, but in consequence of the rotation of the Earth the actual flow of the wind is that stated in the law of deviation (p. 58). The deviation is proportional to the latitude, so that in the far north and south, wind blows nearly parallel to the isobars. Buys Ballot, the late eminent Dutch meteorologist, discovered the *Law of the Winds*, which may be put in this form:—"Stand with the Low pressure on your Left hand and the high pressure on your right; then in the Boreal (northern) hemisphere the wind is Blowing on your Back; but in the southern hemisphere in your face." The student should confirm these statements by studying Plates V. and VI.

Winds of the Southern Hemisphere in January.—The theoretical arrangement of atmospheric pressure and winds (pp. 129-133) is changing from hour to hour in response to the changes of day and night (p. 135) and summer and winter (p. 136). The two maps (Plates V. and VI.—which should be referred to continually in reading what follows) are reduced from Buchan's *Challenger* maps, and revised by the more recent maps of Hepworth and Mohn; they give the average conditions in January and July. In the map for January the equatorial zone of low pressure, as limited by the isobars of 29·90 inches, is narrow over the ocean but widens greatly over the three southern continents, where the heat of summer causes the air to ascend, flow away, and reduce the pressure over the land. Another consequence of high temperature over the continents is that the south tropical belt of high pressure is broken into three isolated portions lying in the main south of the tropic in the three oceans. The southern area of low pressure and of steep gradient apparently forms a zone between 50° and

70° S. The observations of Antarctic explorers indicate a higher pressure over the Antarctic continent, producing easterly and southerly winds south of the Antarctic Circle. From the three south oceanic regions of high pressure, surface winds blow outward, forming the south-east trades on the northern margin towards the equatorial low pressure, and the brave west winds on the southern toward the Antarctic low pressure. The portions of the equatorial low-pressure zone extended to the south by the continents produce monsoons, or an indraught of surface air toward the land. On the north-west coast of Australia the Australian low-pressure area draws the trade wind round to form a north-west monsoon. On the west coast of Africa the south-east trade is drawn in to form a light south-west monsoon, and in the Gulf of Guinea it is drawn in strongly from the west. The same action is seen on the west coast of South America, but there the uniform face of the Andes appears to deflect the wind. On the eastern shores of the southern continents the monsoon effects strengthen the prevailing trade winds.

Winds of the Northern Hemisphere in January.—The north tropical zone of high pressure forms a continuous belt round the world, narrow over the oceans, but extending right up to the polar regions over the two northern continents. Over these continents air is concentrated and the pressure comes to a maximum in the middle of northern Asia and of North America, the high pressure of the two continents forming a broad ring round the pole. The pressure and the winds within the Arctic Circle have been laid down by Professor Mohn in his discussion of the observations made by Dr. Nansen in the *Fram* in 1894-96. The Arctic low-pressure area is cut up into two comparatively small depressions, one with its centre between Iceland and Greenland, the other in the North Pacific Ocean. In consequence of this arrangement the north-east trade winds of the

Atlantic blow into the Caribbean Sea and against the coast of South America beyond the equator, and, under the influence of the South American low-pressure area, unite with the south-east trades, blowing up the valley of the Amazon, so that there is no calm belt between the Trades on that coast. The North Atlantic low-pressure area, while maintaining the south-west winds of western Europe, draws in cold north-east winds on the east coast of North America. The high pressure over North America gives rise to monsoon winds which attain considerable force as north-westers along the west coast of Central America, and also sets up prevailing northerly winds down the Mississippi valley.

Winter Monsoon of Indian Ocean.—About the month of October, when the pressure over the great Asiatic continent becomes higher than that over the ocean, light northerly winds set in in the Bay of Bengal and the Arabian Sea, gradually changing to north-east winds at sea, where they represent the trade winds, but rarely attaining great force, and often broken by calms. Along the base of the Himalayas in the plain of the Ganges the wind is north-westerly. This state of matters lasts for several months, coming to a climax in January. Over most of India it is a dry season, as the air of the North-East or Winter Monsoon has descended from the upper region of the atmosphere, and contains little water-vapour. On the east coast of the Indian peninsula and of Ceylon, the north-east wind having traversed the Bay of Bengal, sweeps along a considerable amount of vapour, which is precipitated, usually during the passage of cyclones, on the Eastern Ghats and the eastern side of the Ceylon hills, winter being their rainy season.

Winds of the Southern Hemisphere in July.—Notwithstanding the change from summer to winter in the southern hemisphere, the southern ring of low pressure is practically unaltered in position, but the gradient is somewhat reduced, and the winds of the Roaring Forties blow with slightly diminished strength. The south tropical belt of high pressure has reunited, except in the western Pacific, by the cooling of the southern continents, and stretches far north of the tropic. In consequence of the small range of temperature and slight winter cooling of the southern continents, the highest pressure in the southern hemisphere is over the oceans even in winter, and this fact accounts for the permanence and steadiness of the brave west winds. The south-east trades blow across the equator far to the north in all the oceans. In the Indian Ocean the calm belt is completely obliterated on account of the great indraught towards Southern Asia which draws supplies from the southern hemisphere and turns the south-east trade winds to feed the South-West Monsoon. At the same time pressure is high over the continent of Australia, from which monsoon winds blow outward. The intense winter radiation from the great interior plateau of Antarctica produces an outward flow of chilled air giving rise to violent blizzards on the coast. Surges of atmospheric pressure radiating from the South Pole traverse the Southern Ocean producing frequent storms of great intensity.

Winds of the Northern Hemisphere in July.—The equatorial belt of low pressure extends over the whole land surface of the northern hemisphere and unites with the north polar region of low pressure, centres of lowest pressure lying in the south-west of Asia and in the west of North America. The north tropical belt of high pressure is broken into two great isolated high-pressure areas, which occupy the North Atlantic and the North-West Pacific, keeping up the north-east trade winds in those oceans, and giving rise to south-westerly winds over eastern North America and North-Western Europe. The monsoon influence of North America is very slight, on account of the position of these two high-pressure areas, and that of North Africa is also remarkably feeble (p. 136). The winds of the Indian Ocean and Western Pacific are dominated by the indraught towards Asia, which attains its maximum effect in July, and disturbs the theoretical atmospheric circulation of the northern hemisphere.

Summer Monsoon of the Indian Ocean.—Round the coast of Asia the north-east wind falls off in February, and gradually shifts to the south as the winter high pressure over the continent is reduced, and gives place to the summer low pressure. March and April are characterised by variable winds and frequent storms. By May the north-east wind has died away, and in its place south-west winds, usually spoken of in India as *The Monsoon*, blow strongly across the Arabian Sea and Bay of Bengal, and wheel round along the foot of the Himalayas, blowing up the Ganges valley as south-east winds. These are really an extension of the south-east trade wind drawn across the equator into the northern hemisphere. This state of matters lasts until August or later. As the wind blows for a long distance over the heated surface of the ocean it is laden with vapour when it reaches land, and, rising up the steep and uniform slopes of the Western Ghats, condenses in tremendous showers. The first deluges of rain are known as the bursting of the monsoon. A heavier rainfall reaches the western edge of the Indo-Chinese peninsula, and the heaviest of all—at one place over 500 inches a year—is found on the hills bordering the valley of Assam. After August the south-west monsoon diminishes in force and gradually dies away as the pressure over the land increases. The monsoon owes much of its strength to the energy set free by the condensation of the vapour it carries. On the coast of China the summer monsoon blows from the south-east, and the winter monsoon from the north-west.

Yearly Swing of the Atmosphere.—The disturbing effect of land and sea on the normal arrangement and movements of the atmosphere may be put briefly thus: In winter the chilled land draws down the blanket of air which the less-cooled sea is tossing off upward. In summer the heated land throws off as much of its air-covering as possible, piling it upon the colder sea which eagerly draws it down. While the land is throwing off the air above, which descends upon the sea, the sea commences to return it to the land along the surface, at first more slowly than it receives it, afterwards more rapidly. At the opposite season, when the land has drawn down on itself from above a greater supply of air, the sea gradually draws it off along the surface. There is thus a constant effort to restore the equilibrium of the atmospheric covering between land and sea, disturbed by the rapid radiation of the land. The prevailing winds of the year, disregarding minor seasonal changes, are shown in Plate VII.

Rainfall and Evaporation.—A continual circulation of water takes place between the hydrosphere and atmosphere. Sea winds carry water-vapour against the land and ascending currents raise it high into the atmosphere, where it condenses and returns either directly as rain or through springs and rivers to the sea. The amount of evaporation at sea and of rain falling on land depend mainly on temperature and winds. Sir John Murray calculated that every year nearly 130 million million tons of water, or about $\frac{1}{40}$ of the whole mass of the atmosphere, are transferred from the sea surface to the land, and find their way back again in rivers. More than half of the rain falls between the tropics, and probably not more than $\frac{1}{10}$ of it reaches ground as snow beyond the polar circles. The average rainfall of the globe is probably about thirty-three inches. A calculation has been made that one quarter of the land surface has a rainfall less than one foot in a year, one quarter has a rainfall between one and two feet, one quarter, of which the British Islands form part, has a rainfall of between two and four feet, and over the remaining quarter the rainfall exceeds four feet in a year. In all regions not reached by sea winds the rainfall is very slight and evaporation preponderates, a nearly rainless area containing dwindling salt lakes occupying part of the interior of each continent (p. 303).

Distribution of Rainfall.—Plate VIII. shows the rainfall on the land by blue and green tints according to the number of inches which fall at each place in a year. It also shows, from the data of several recent oceanographical expeditions, the salinity of the ocean surface by red tints. Salt areas in the sea are produced by evaporation of the water which supplies the rainfall of the land, and they may be termed the comparatively dry regions of the sea. They correspond very closely with the centres from which the trade winds blow. The lightest blue colour on the map denotes regions where the rainfall is under ten inches per annum. These correspond exactly with the regions of extreme range of temperature, lying as a rule in the interior of continents. The regions of greatest rainfall coloured in darkest green are tropical plains or steep slopes exposed to sea wind. In North America, for example, the trade winds blowing round the Gulf of Mexico, and the south-west winds beating on the coast of Oregon and British Columbia, ensure heavy rainfall. South America shows a very interesting relation. In the trade-wind region vapour is carried up the flat valley of the Amazon and condensed on the eastern slope of the Andes, the western slope of which is rainless. In the south of the continent the west winds of the Roaring Forties dash perpetual showers against the western face of the Andes, and descending sweep as drying winds across Patagonia. In India and also in the Malay Archipelago the heavy rains are produced mainly by the summer monsoons. Attentive study of the rainfall map, along with those of winds and configuration, will bring out similar reasons for the local distribution of rainfall in all parts of the Earth.

Winds of the British Islands.—The British Islands are usually covered by the edge of the North Atlantic area of low pressure. The pressure being lowest in the north-west, and highest in the south-east, corresponds to prevailing south-westerly winds. In January the isobars are closely crowded together; in that month the average gradient over the British Islands is steeper, and the winds are consequently stronger than in any other part of the world. From January onward the atmospheric pressure increases rapidly in the north and much more slowly in the south, so that in the month of April the gradient though still for westerly winds, is very slight. A small temporary rise of pressure in the north may then reverse the gradient, and as soon as the pressure in the north becomes higher than that in the south, east wind sets in. A similar state of matters occurs again in November, on account of the pressure in the south falling more rapidly than that in the north, and the months of April and November are famed for bitter east winds in most parts of Great Britain.

Temperature of the British Islands.—The mean temperature of the British Islands as a whole for the year is about 48°, increasing from 45° in Shetland to 53° in Scilly, or an average rise of temperature of 1° for every 100 miles toward the south. In winter the temperature has little relation to the latitude, the islands grow colder from west to east, the heat coming from the sea, not directly from the Sun. The isotherms of January (Plate X.) run in general parallel to the coast. Large areas on the east coast from Caithness to Essex have a mean air temperature of 38° or less. Orkney, Western Scotland, Mid Wales and the Isle of Wight are all at 40°, while the tips of Kerry and Cornwall are above 44°. The south of England is mild in winter, not because it is the south, but because it runs so far to the west. By the month of April the isotherms run nearly east and west, the direct supply of heat from the Sun dominating the distribution; the mean temperature is 42° in Shetland, 45° from Skye to Aberdeen, and 48° from Erris Head through Dublin and Liverpool to Harwich. During April land and sea have practically the same temperature. In July the land has heated up more than the sea, so that the south-west wind now has a cooling effect, and the isotherms (Plate IX.) run roughly from S.W. to N.E. Shetland is at 54°, the line of 58° runs from Malin Head, passing near Stranraer and Glasgow to Aberdeen, and that of 60° encircling the south-east of Ireland, runs north from South Wales to Yorkshire. The warmest region is round London, where the temperature averages 64°. As autumn advances the air cools down most rapidly on the east coast, and in September the isotherms run west and east once more, and the temperature varies from 52° in Orkney to 58° along a line from Pembroke through Bristol and Reading to Lowestoft. The way in which proximity to the sea and exposure to the prevailing winds influences the range of temperature is shown in the following tables:—

	Shetland	Rothesay	Plymouth	Inverness	Edinburgh	London
Jan. temp.	39·5	39·5	43·0	37·5	38·0	39·0
July temp.	53·5	58·0	62·5	58·0	59·5	64·0
Annual range	14·0	18·5	19·5	20·5	21·5	25·0

If it were not for the warm south-westerly winds the January temperature would be 7·5° in Shetland, 12·5° at Edinburgh, and 22° at London, and the sea all round the islands would be frozen, as in Labrador which lies between the same parallels of latitude.

The Rainfall of the British Islands has been studied in greater detail than that of any other country, thanks to a voluntary organisation of observers initiated by the late Mr. G. J. Symons in 1860, and including over 5,000 stations in 1923. While heavy showers of rain show little relation in their distribution to the forms of the land, the average rainfall of any country is mainly determined by the configuration and the prevailing wind. The rainfall at the same height above sea-level is greatest on the west and least on the east coast, warmth always going with wetness (Plate XVI., compare also Plate

XVII.) In Ireland, on account of the mountains forming irregular isolated groups, the rainfall is remarkably uniform over the low-lying part of the island, averaging about forty inches in the year. In Great Britain the low outer Hebrides have a rainfall of about forty inches, but the high mountains of the Western Highlands condense more than eighty inches in the year over an area stretching from Skye to Loch Lomond. The mountains of Cumberland, the Pennine chain, and Wales and the high land of Cornwall and Devon have also a large rainfall; but the whole east of Britain has less than thirty-five inches. Most of the district between the Humber and the Thames, the driest part of the British Islands, receives less than twenty-five inches of rain per annum. Contrary to the usual opinion, November is nowhere the rainiest month in the British Islands. The heaviest rainfall in the west and north of Ireland and the west of Scotland takes place in December or January. In England and the east of Scotland it occurs in October, except in the very dry region between the Thames and the Humber, where most rain falls in July or August on account of thunderstorms. In the south of England the least rainy month is March, in the north of England and south of Scotland it is April, in the west and north of Scotland it is May or June.

The average climate shown in the maps, although correct on the whole, cannot be depended upon to hold good at any special place for any particular month. Such maps are of great value in choosing a place to reside in, but of very little use for planning a pleasure trip. As much as nine inches of rain may fall in a single day in any part of the British Islands, though falls exceeding four inches in a day are very rare indeed.

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CHAPTER X

WEATHER AND STORMS

Weather.—The conditions of climate referred to in the last chapter represent the average state of the atmosphere, but in any particular place they are subject to considerable disturbances from day to day. Thus, although the prevailing winds of the British Islands are south-westerly, many days occur on which the wind blows from the north-east, and indeed the direction often changes from hour to hour. The actual condition of wind, temperature, humidity and rainfall is referred to as weather, and just as climate shows a distinct relation to the average isobars and isotherms of a region, so weather stands in a definite relation to the isobars and isotherms which represent the condition of the atmosphere at any moment, and which are always undergoing change both in form and gradient. Fig. 29 shows the isobars and resultant winds over Western Europe at a particular moment, and it will be observed that the high-pressure areas called anticyclones (A), and low-pressure areas called cyclones (C), appear in it, as well as various other groupings of the isobars with which special varieties of weather are associated. The weather of any region depends largely on the place of origin of the air which is passing over it at the time; thus a current of warm, moist air sweeping in from the ocean naturally produces mild, showery weather as it passes over a tract of undulating country. On the other hand, a current of air blowing from a large stretch of snow-covered land carries with it cold, clear weather, but may at its first onset produce heavy rain by flowing under and raising up the warmer, moister air of an oceanic atmospheric current.

Isobars and Actual Winds. — In treating of average isobars and the associated winds it was fair to assume that the air circulated in an outward spiral round regions of high pressure and in an inward spiral round regions of low pressure, the whole circulation being perfectly symmetrical and very simple. Until recently it has been usual to make the same assumption with regard to isobaric maps representing the distribution of pressure at a given instant of time. When such maps—for instance, those prepared by the Meteorological Office for 7 A.M. and 6 P.M. daily—are examined, it is found that two types of isobars are the most common, though several other types occur. Of the two, one represents a region of low pressure with winds blowing nearly parallel to the isobars, but directed inward, as shown in C (Fig. 29), and this, on account of the apparently circular

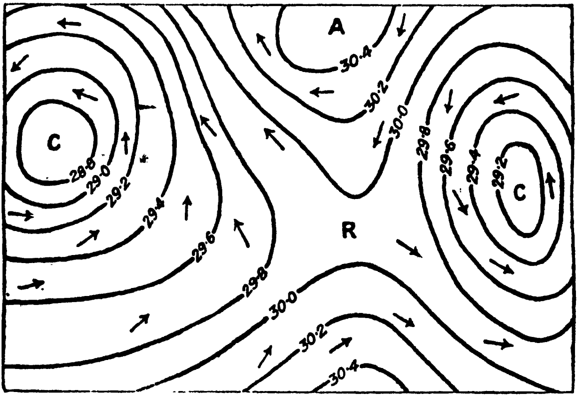

FIG. 29.—Isobars showing two cyclones (the centres marked by C) separated by a ridge of high pressure, R; and also an anti-cyclone, A.

movement of the wind round the centre, is known as a cyclone. The other represents exactly the opposite condition, that is, a region of high pressure round which the winds blow nearly parallel to the isobars, but directed outwards, as shown in A (Fig. 29), and this has been termed an anti-cyclone, as its characteristics are, on the whole, the opposite of those of a cyclone. If the position of the centres of high and low pressure remained stationary, the air would blow spirally outwards along the surface from the anti-cyclones, and it would blow spirally inwards along the surface into the cyclones. There, in order to keep up the movement, it would have to rise vertically, and, flowing outward in the higher part of the atmosphere, descend in the central area of the anti-cyclones exactly as is the case on the average in the areas of permanently high and low pressure over the Earth's surface. Sir Napier Shaw has shown, by charting the movements from hour to hour of particles of air in connection with actual cyclonic or anti-cyclonic systems which are not stationary, that the circulation of the winds associated with them is really unsymmetrical and rather complicated. At every instant of time the actual distribution of pressure tends to produce winds circulating round the centres of low pressure, but long before such circulation can be completed the centres have moved onwards, and the actual trajectories of the air show rotation round the moving storm centre to only a slight extent. The more rapidly a cyclone moves, the less complete is the circulation of air about its centre, but in the very slow-moving cyclones of the tropics it is possible that a complete circulation with indraught to the centre from all sides is really set up. The older theory of cyclones and anti-cyclones was very simple and easily understood. The cyclone was viewed as a whirl of surface-air inward and upward; the anti-cyclone as a whirl of surface-air downward and outward. This accounted in a general way for the succession of weather found in both systems, but it did not take account of the fact that a cyclone was always in motion over the surface, while an anti-cyclone was generally at rest. Dr. J. von Hann, of Vienna, had pointed out that the cyclones and anti-cyclones of the temperate zone were not produced locally, but were incidents in the great currents of air which carried on the circulation of the atmosphere, similar to the swirling eddies in a rapid stream of water, thus suggesting that the differences of pressure in such forms were due to the winds rather than that the winds were due to the differences of pressure. On theoretical grounds Dr. V. Bjerknes explains the origin of temperate cyclones and anti-cyclones by waves set up in the surface between the cold stream of polar air and the warm stream of tropical air flowing over it in the course of atmospheric circulation. Sir Napier Shaw looks on anti-cyclones as masses of air which for some reason are not taking part in the atmospheric circulation around them, with which cyclones from their very nature are actively associated.

Anti-cyclones.—An anti-cyclone is a portion of the atmosphere in which the pressure is highest at the centre and diminishes nearly uniformly and with a gentle gradient in all directions, giving rise to light winds, variable near the centre, and in the northern hemisphere with a circulation of surface wind round the edge in the same direction as the hands of a watch move; in the southern hemisphere in the opposite direction. When once formed, this arrangement of pressure is very stable and usually lasts for many days or even weeks at a time. In such circumstances strong streams of air may flow for a long distance round the system nearly parallel to the isobars. A striking instance of this is shown in Fig. 30, which represents a great anti-cyclone central over Spain, while the wind blew in a curved path from North-West Africa to England, the proof of the continuity of this wind being afforded by the copious fall on the south of England of fine red dust carried from the Sahara desert. Anti-cyclones were formerly held to be regions of dry descending air, where the weather was typically cloudless and radiation could produce its maximum effect, leading to great heat in summer and intense cold with fogs in winter. Such weather does indeed frequently occur in anti-cyclones, but is not confined to such conditions, and Mr. W. H. Dines showed that the weather of anti-cyclones in the British Islands was inconsistent with the theory that they are formed of dry descending air. A distinction must be drawn between the inert mass of air in a typical anti-cyclone which remains stationary over a particular tract of country for many days and the area of high pressure separating two successive cyclones (Fig. 29) and travelling with them. The latter are apparently regions of descending air which feed the cyclones on either side, and in them the type of weather associated with dry air and unchecked radiation does undoubtedly occur.

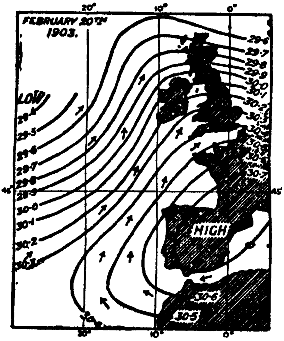

Fig. 30.—Isobars and Winds of Anticyclone of February 20th, 1903.

Temperate Cyclones and Cyclonic Weather.—Speaking generally, cyclones may be said to form most often on the edge of the permanent regions of high pressure along the margins of which they travel. In the northern hemisphere the direction of motion of cyclones as shown by the track of the centre is usually westward in the tropics, gradually turning to the right and becoming north-eastward in high latitudes. In the southern hemisphere it is also westward in the tropics, turning toward the left and becoming south-eastward in high latitudes. In the temperate zone the rate of motion of the centre may be from 15 to 30 miles an hour, a speed which is often greater than that of the accompanying winds.

This fact of itself shows that the circulation of the wind round the centre cannot be complete. Whatever theory be held as to the circulation of air in a cyclone, experience shows that there is in every atmospheric depression a similar distribution of weather, and that while the distribution of the weather depends on the form of isobars, its intensity depends on the gradient. An observer in the track of one of the common winter cyclones of the British Islands usually gets the first intimation of its approach from the appearance of a solar or lunar halo which is produced by the reflection of light from the minute ice-spicules which later form a display of cirrus cloud. This shows that a rapid vertical movement of air is in progress, leading to the condensation of water vapour. The barometer is next observed to begin to fall, and the rate of fall indicates the rate at which the centre of the cyclone is approaching and the gradient of the pressure. The sky becomes gloomy with dense clouds, rain falls heavily, while the wind is changing from south-east through south

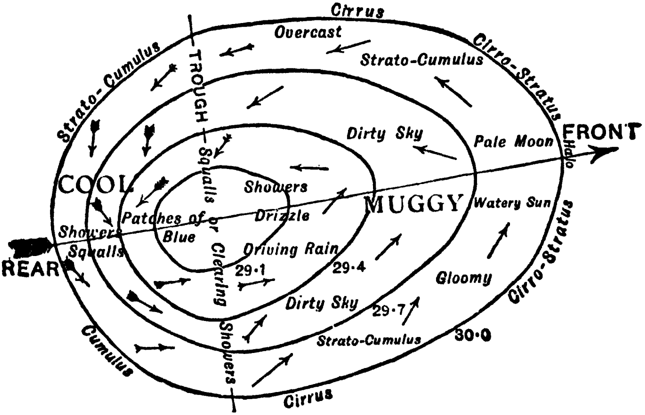

FIG. 31.—Isobars of a Cyclone. (After the Hon. Ralph Abercromby.) Direction of wind and distribution of weather shown for the north temperate zone.

and west on the south of the track and from south-east through east to north on the north of the track. When the barometer ceases to fall the wind drops to a calm, and when it begins to rise again the centre of the cyclone has passed. The wind then shifts to north-west or north, increasing in force, the sky clears and the air becomes peculiarly exhilarating. Fig. 31 shows the form of the isobars, direction of wind, and the different kinds of weather in various parts of a typical cyclone of the north temperate zone, the long arrow showing its direction of motion. The distribution of rainfall is not symmetrical with respect to the track of the centre except in rare cases, probably when the track is a straight line. In ordinary circumstances, when the track of the centre is curved, the heaviest rainfall appears to occur on the left of the track, irrespective of the direction in which the centre of the system may be moving. A good example of heavy precipitation on the left of the track is shown in Fig. 32, which represents a

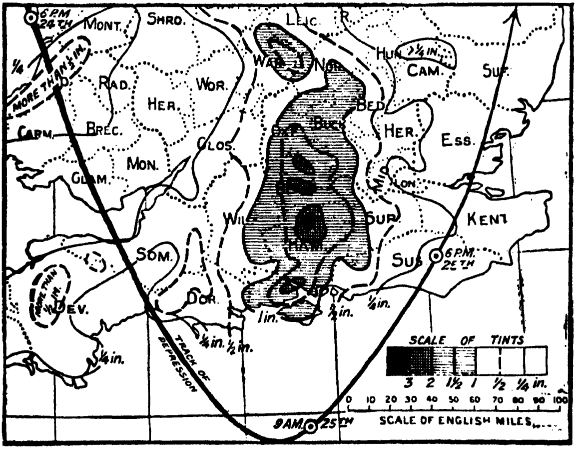

FIG. 32.—Snowstorm of April 25th, 1908, in the South of England, with track of the secondary cyclone which caused it. The isohyetal lines express precipitation in terms of rainfall.

severe snowstorm produced by a small secondary cyclone in which there was almost no precipitation on the right of the track.

Mechanism of a Temperate Cyclone.—Sir Napier Shaw holds that the essential factor in a northern temperate cyclone is the warm, moist southerly wind which forms the eastern flank. This is met about the line of the track of the centre by a dry, cold easterly wind, which may enter the depression from the south-east, east or north-east; and finally there is a cold and relatively dry wind coming from the west or north-west, perhaps even from the north, curving round the rear of the depression. The meeting of these winds from different quarters carrying air of different origins and at different temperatures gives rise to the sudden changes of temperature and wind direction which are familiar in actual cyclones, though not readily explained on the old hypothesis of uniform circulation. When a cold and a warm current of air meet they mix only in part, while the bulk of the cold current passes under the warm, which is thus forced to ascend and produces heavy rainfall by the condensation of its vapour.

Squalls.—Violent squalls of wind sometimes occur simultaneously along a line which advances rapidly across the surface, its passage being accompanied by a sudden sharp rise and fall of the barometer and change in the direction of the wind, very often by a thunderstorm and a heavy shower of rain or hail in summer or snow in winter. The shower is usually of short duration, but, like the wind, of great intensity. This effect has been traced to the inrush of a current of cold air which disturbs and thrusts itself under the warmer air moving from a different direction and already occupying the space that is invaded. The line of the squall front is usually at right angles to the isobars of a cyclone, and occasions are known in which the length of this line was over a thousand miles, while it moves forward at rates varying from 20 to 50 miles an hour.

Tropical Cyclones.—Small cyclones of slow motion but with steep gradients, and therefore accompanied by very severe winds, are common in the tropics at certain seasons. Among the West Indian Islands such storms are liable to occur during the months from July to October, and their terrific violence has given wide currency to their native name of *Hurricanes.* In the Bay of Bengal and along the east coast of Africa, similar storms, to which the name *Cyclones* was first applied, are experienced, accompanied by torrential rainfall. In the China Sea they are common from July to November, and are known as *Typhoons.* These tropical storms differ from the less violent cyclones of the temperate zone in always having a patch of clear blue sky over the central calm where the barometer is lowest; this is called the eye of the storm. It is probable that in such slow moving storms there is a complete circulation of the wind round the centre. Although the calm centre of a cyclone is referred to poetically as "the whirlwind's heart of peace," it is the part most dreaded by sailors. There is no wind to move a sailing ship, and a terrible chaos of heavy waves is driven in by the winds raging on every side. A ship-captain in the season when these storms are prevalent is always on the watch for them, their approach being heralded by a rapid fall in the barometer. The way in which the wind changes enables one to ascertain the position of the centre, and thus a steamer by changing its course can often avoid the worst of the storm.

The commonest cyclone tracks of the tropics and the usual direction of motion of the storm-centre are represented on Plate VII.

Whirlwinds.—Eddies of ascending air which are of small diameter compared with their height, and move rapidly forward over the Earth's surface, are called *Whirlwinds.* They may be set up by the sudden heating of the lower layers of the atmosphere or perhaps by the meeting of strong currents of air moving in different directions. The dreaded *Simoom* of the Sahara is a whirlwind which raises great gyrating clouds of sand, and sweeps forward with irresistible force, darkening the sky at midday. The *Tornado* of North America is most often formed in the south-east side of a slowly moving cyclone, and usually acquires its full force suddenly in sultry summer afternoons. The origin of a tornado has given rise to much controversy, but is usually believed to be due to the rapid heating by the sun of a lofty column of air fully charged with water-vapour. The heated air expands upward and rotates as it rises, drawing the surface air in from all sides. The water-vapour, condensing as the air cools in ascending, adds to the heat-energy of the whirl, and helps to produce a tremendous reduction of pressure in the centre. Surface winds rush into this partial vacuum, and whirl with terrific violence up the central hollow as if it were a furnace chimney. In consequence of their force the tornado cuts a clean path through forests or towns that lie in its track. The breadth of the zone of destruction is seldom more than a quarter of a mile. Houses are not simply knocked down, but burst up when a tornado passes over them. The low pressure of the centre creates a partial vacuum, and the air inside a house consequently expands so rapidly that the roof is blown off and the walls are thrown outward. Sheep and fowls when caught up are completely plucked of wool or feathers by the fierce whirls of wind before they are dropped. After about an hour the heated vapour-laden air that originates the tornado is dispersed, and as the whirl travels at the rate of about 30 miles an hour, the track of destruction is usually 30 miles long, although instances of papers being carried 45 miles are on record. Tornadoes are most common in the United States east of 100° W.; but it is only in a small district of Kansas on the Missouri River, and in the south-west of Illinois, near the Mississippi and Ohio, that more than 50 have been recorded in a hundred years.

Waterspouts and Cloudbursts.—The rapid condensation of water-vapour in the axis of a tornado, or in the comparatively harmless whirlwinds that sometimes occur in all parts of the world, produces a dark funnel-shaped cloud tapering downward to the Earth. Such a cloud occupying the centre of an ascending eddy of air is called a *Waterspout.* When it strikes the ground the heavy fall of rain on a very small area sometimes produces great destruction. At sea, or in passing over a lake or river, the low pressure of the whirling air of a waterspout often sucks up a column of water and whirls it on for considerable distances. In this way shoals of fish or swarms of frogs have been known to be raised high in the air, carried for miles inland, and dropped as showers of fish or frogs, to the wonder of country people. It may happen that the upward rush in a tornado is strong enough to prevent the condensed water from falling until a great quantity has accumulated; then it descends not as rain, but like a river, and the phenomenon is spoken of as a *Cloudburst.* On mountain slopes cloudbursts have been known to hollow out deep ravines in a few minutes, the marks of which have not been effaced by ordinary weathering in a century or more. Hail as well as rain may be similarly accumulated, and the worst hailstorms occur during the passage of a tornado.

Weather-charts.—The gradual growth of our knowledge of the atmosphere showed that the barometer could be used for predicting changes of weather in certain cases. Most barometers have a series of words from "Set fair" to "Stormy" engraved on the scale, as if high or rising pressure always means calm and fine weather, and low or falling pressure always fortells wind and rain. A few weeks' observation will in most cases convince anyone that this is a mistake, and that a single barometer is of little value in forecasting the weather. Fig. 30 shows that it is not the actual height of the barometer at one place, but the difference in the height of many barometers at considerable distances apart, that can throw light on the state of the atmosphere and the associated weather. Synoptic charts showing the isobars at a given hour once or twice a day enable storms to be foreseen in many cases. In all civilised countries there is now a number of meteorological stations where observations of barometer, thermometer, wind, etc., are made at the same hour morning and evening, and telegraphed to a Central Meteorological Office maintained by Government. Here charts are prepared showing at one glance the state of the atmosphere both as regards pressure and temperature (corrected to their value at sea-level) over the whole country and surrounding areas. If the student will take the trouble of tracing in red ink on thin paper the isobars given above in Figs. 29 and 31, and will then lay this tracing over the map of the British Islands (Plate IX.), he will see in a general way how the weather varies in the different parts of the country according to the distribution of the various types of atmospheric pressure.

Weather Forecasts. — Several arrangements of isobars besides those into cyclones and anti-cyclones may occur. Isobars drawn from actual observations may be straight, showing that they form part of neither cyclone nor anti-cyclone ; sometimes they are sharply curved, forming V-shaped areas of low pressure or wedge-like areas of high pressure lying between adjacent anti-cyclones or cyclones ; and they very often form loops, showing the existence of a small secondary cyclone inside a larger. Each type of pressure-distribution corresponds to a special kind of weather, and the relation between isobars and weather has been carefully studied and is well known to practical meteorologists. The commonest weather in the British Islands is that produced by the passage of cyclones eastward from the Atlantic, and this may be taken as a characteristic example to illustrate weather forecasts. If the student places a tracing of Fig. 31 on Plate X. so that the large arrow points north-east and its head is on the south-west of Ireland, and then moves the tracing gradually north-eastward, he will see how the weather varies in all parts of the islands as the cyclone passes along its path. By shifting the centre to north or south, and changing the direction of passing (but always moving the tracing as the arrow flies), the effect on the student's own locality of cyclones passing in any direction may be followed. Remembering that as isobars of successively lower value are passing the barometer is falling, and that as isobars of higher value are passing the barometer is rising, it will be found possible to identify the actual movements of a cyclone by watching the barometer and the changes of wind and weather. In order to predict on Monday the kind of weather and direction of wind on Tuesday when a cyclone is passing, it is necessary to know where the centre is, at what speed, and in what direction it is moving, so that a map of the conditions expected on Tuesday can be drawn up from the data supplied by Monday's observations. But in order to predict the intensity of the weather and the force of the wind, it is necessary to know whether the cyclone is "deepening" or "filling up," that is, whether the gradient of pressure from circumference to centre is growing greater or less. Only experience and practice can guide a forecaster in these matters, and the success of the predictions depends on the knowledge and skill of the men who make them. It often happens that a cyclone does not follow the usual path, or that the pressure at the centre increases when the forecaster thought it would diminish, or that a secondary depression suddenly forms in an unexpected place, and of course in all such cases the forecast made is a failure. Yet on the whole more than 80 per cent. of the predictions issued in Britain and America are successful. Every morning and evening forecasts for the next 30 hours of the weather in each of the districts into which the British Islands are divided for the purpose are published at the Meteorological Office in London from observations made at 7 A.M. and 6 P.M. all over the country, as well as at many stations on the Continent, in Iceland and the Azores, with occasional reports by wireless telegraphy from ships at sea. The weather-charts and reports in a daily, weekly and monthly form are sent out to subscribers by the Meteorological Office, the forecasts from the 7 A.M. observations being issued with the Daily Weather Report, and all forecasts are supplied regularly to the Press.

Storm Warnings.—A sudden fall of the barometer at any of the special meteorological stations is at once telegraphed to the Central Meteorological Office of each country, and if it is found to indicate the discovery or sudden deepening of an approaching cyclone which is likely to cause a dangerous storm at sea, warnings are telegraphed to all the important harbours and fishing stations on the coast, where signals are immediately hoisted to give notice to fishermen and sailors. Such signals in Great Britain are most valuable on the east coast, where, as the disturbances usually come from the west, the warnings can be received in time to be of use. Farmers as well as sailors profit by weather predictions, particularly in the hay and harvest seasons. The escape of gas in coal-mines and consequent risk of explosions is supposed to depend largely on variations of atmospheric pressure, and useful miners' warnings were formerly issued by an unofficial and anonymous agency when any serious change of pressure over the coal-mining regions was anticipated. In many ways the British Islands are in the worst position for forecasting the weather, as they lie in the most disturbed region of the atmosphere. When the system of wireless telegraphic weather reports from Atlantic steamers is perfected, the storm warnings will doubtless improve in certainty and increase in number. On the continent of Europe forecasting is comparatively easy, as the British stations give early notice of many changes. Similarly, in a broad stretch of land like North America, Australia, or India, where the stations are widely distributed and well equipped, there are great advantages for the prediction of weather. In the United States the Weather Bureau of the Agricultural Department has charge of meteorological observations, and the forecasts from the central Bureau are supplemented from many district offices. In America the economic value of forecasts of frost is keenly realised by the fruit farmers, who frequently save their crops by taking precautions when the warnings are issued. The attempt to time the arrival on the coast of Europe of cyclones whose path across America has been tracked out is rarely successful, as most depressions either fill up or change their path or rate of moving on the way across the Atlantic. There are many prognostics or signs, such as the appearance of halos, of mist on hill-tops, great clearness of the atmosphere, exceptionally bright reflections in water, the movements of animals, by which experienced people can foretell the weather of their own district with marvellous correctness. Indeed, for any mountain valley or seaside town the opinion of an observant old shepherd or fisherman on the approaching weather is likely to be more correct than the Meteorological Office forecast, which is necessarily somewhat general.

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CHAPTER XI

THE HYDROSPHERE

Land and Water.—The hydrosphere does not completely cover the globe, because the lithosphere which supports it is diversified by great heights and hollows. The portion of the heights projecting above the water surface forms land, which is estimated at the present time to cover 29 per cent. or a little more than one quarter of the globe. Most of the hydrosphere is retained in the great world-hollows forming the ocean, which covers about 71 per cent. of the surface; but on account of evaporation and condensation a small part is always present as vapour in the air, and a certain amount rests as lakes in hollows of the land or flows across the surface in rivers. The proportion of land and water in different latitudes is represented in Fig. 33, where the land area is indicated by shading. The largest proportion of land is in the northern hemisphere, where it occupies about 42 per cent. of the surface, while water largely predominates in the southern hemispere, where about 17 per cent. of the

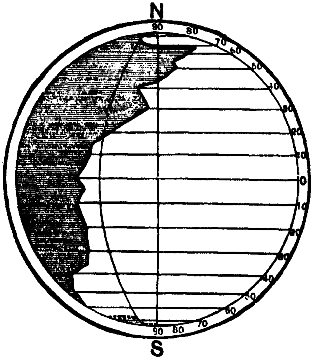

FIG. 33.—Proportion of land and sea in different latitudes. Land area shaded (after Krümmel).

surface is dry land. The uniform curve in the figure shows the average distribution of 29 per cent. of land in all latitudes. All the great land masses of the globe are widest in the north, and taper to a point toward the south. Only a few small islands lie between 56° S. and the Antarctic Circle, south of which the continent of Antarctica extends, and it appears probable that south of 80° S. there is practically all land with only a small amount of frozen sea. The inequality of the distribution of land and water appears greatest in the hemisphere having its centre near New Zealand, which comprises two-thirds of the entire ocean surface and not much more than one-eighth of the land; and in the opposite hemisphere (with its centre in the English Channel) which contains only one-third of the ocean and seven-eighths of the land of the Earth. In the water hemisphere the proportion of land is about $\frac{1}{12}$ or 8 per cent.; in the land hemisphere it is about ½ or 50 per cent., the areas of land and sea being equal (see small maps on Plate XI.).

Divisions of the Hydrosphere.—The Caspian Sea is the only large sheet of water which is cut off by land from the rest of the hydrosphere, and its separation from the ocean is comparatively recent. Otherwise the hydrosphere is a connected whole, made up of four wide open expanses called *Oceans*, from which smaller portions called *Seas* are more or less distinctly marked off by the land. It is a matter of opinion where to draw the line between oceans and seas; the expanse of water within the Arctic Circle, for example, is by some authorities considered the smallest ocean, and by others with more show of reason it is held to be the largest sea. Seas may be classed in three groups—(*a*) *Inland Seas*, entirely surrounded by land, of which the Caspian is the only example; (*b*) *Enclosed Seas*, nearly surrounded by land but connected with the ocean or with another sea by one channel, which is narrow and shallow compared with the general breadth and depth; (*c*) *Partially Enclosed*

Seas, which (α) have two or more entrances, or (β) are separated from the ocean by a line of islands, or (γ) by an entirely submerged barrier.

The Oceans.—No natural boundaries mark off the hydrosphere sharply into separate parts, but it is convenient to distinguish four divisions called oceans, the positions of which are shown on Plate XIII. The *Southern Ocean* may be characterised as the shoreless ocean, for it extends round the Earth from 40° S. to the Antarctic ice, only a portion of South America, the islands of Tasmania and South New Zealand, and some smaller ones projecting into it. Its area is about 30,000,000 square miles. The *Pacific Ocean*, with an area of 55,000,000 square miles, as large as all the land of the globe, is well called the Great Ocean by the Germans. It contains many islands and partially enclosed seas, the names of which are given in the following table. The Pacific is the only ocean parts of which lie more than 2,500 miles from the nearest continent (see Plate XII.). The *Indian Ocean* is entirely enclosed by land on the north, and has an area of 17,000,000 square miles. The *Atlantic*, with an area of 33,000,000 square miles, has a more indented shore than any other, and may be called the ocean of enclosed seas. The largest of these, often itself termed an ocean, is the Arctic. More than half the land of the globe sends rivers into the Atlantic.

OCEANS AND SEAS

ATLANTIC		PACIFIC		INDIAN	
Enclosed	Partially Enclosed	Enclosed	Partially Enclosed	Enclosed	Partially Enclosed
Mediterranean	Arctic	Yellow	Bering	Red	Andaman
Black	Norwegian		Okhotsk		
Adriatic	Kara	Gulf of California	Japan	Persian Gulf	
Baltic	North		China		
White	Caribbean		Celebes		
Hudson's Bay			Banda		
	Gulf of Mexico		Java		
			Sulu		
			Arafura		
			Tasman		

Ocean Tides.—If the hydrosphere were continuous, or if the land were arranged in narrow strips from east to west, a double tidal wave would travel round the globe every day, the velocity of this free wave form being thus about 1,000 miles an hour at the equator, and its length half the circumference of the Earth. If the land of the globe were arranged in strips from north to south, cutting up the hydrosphere into a series of narrow compartments, there would be no appreciable tidal effect. By the actual arrangement of land there is a free water ring in the Southern Ocean only; there is one long comparatively narrow compartment, the Atlantic Ocean; another wider and shorter, the Indian Ocean; while the rest of the hydrosphere forms the wide surface of the Pacific extending nearly half-way round the globe at the equator. In the Pacific and the adjacent Southern Ocean alone has the tidal wave full room to form, and from them the wave passes westward, being deflected northward into the other oceans. The tidal wave travels most rapidly, and is longest and of least amplitude in deep water; in the central Pacific the range between High Water and Low Water (the amplitude of the tidal wave) is less than 2 feet, and no current is produced. The phrase "tidal wave" is often erroneously used for the great waves raised by earthquakes, which do much damage along the coasts affected by them. A remarkable wave-like rise and fall of the dense salt water of some Swedish fjords with a corresponding thinning and thickening of the fresher surface layer has been shown by Professor Otto Pettersson to coincide with the changes of the Moon's declination, and thus to resemble a tidal effect with a fortnightly period.

Tidal Currents.—When the tidal wave enters shallow water it becomes shorter and moves more slowly. The under side of the wave becoming more retarded than the top, the surface water is carried forward as a true current, the energy of which is derived from the Earth's rotation. In this way shoals or submarine peaks convert the simple up and down movement of the tide in the open ocean into rapid currents, usually for a very short distance, but sometimes extending to a great depth. These are more definite along the shores. The usual tidal effects observed on a broad gently-shelving shore are the gradual rise of the level of the water, the submergence of the beach and advance of the sea on the land; then after the highest point has been attained, the gradual lowering of level with corresponding uncovering of the beach and retreat seaward of the sea-margin. At New and Full Moon, when spring-tides (p. 78) occur, the rise and fall is at the greatest, and then, at any one place, high water occurs at the same hour. Admiralty charts show the tidal data for each seaport, thus, *e.g.* "High Water, Full and Change, X. rise 10 feet." This means that on the day of Full Moon and of Change or New Moon high water occurs at 10 A.M., and the rise of the sea between low water and high water is 10 feet. For such a place each successive high tide after Full Moon occurs at an interval of about 12½ hours, rises to a somewhat less height and falls to a somewhat less depth, thus covering and laying bare a narrower strip of the beach until the Moon's phase is the third quarter, when the time of morning high water is 4 A.M. and neap-tide occurs. After this the tides increase in amplitude again until the period of Change or New Moon, when the time of morning high water is once more 10 o'clock. The time during which tidal currents run in one direction and in the opposite bears little relation to the hours of high water and low water, depending largely on the form of the coast. In partially enclosed seas a branch of the tidal wave usually enters by each channel, as shown in the co-tidal map of the British Islands (Plate XVI.).

Tides in Bays and Estuaries.—When the tidal wave of the ocean enters a narrowing bay or sea inlet, the depth of which diminishes quickly, the tidal currents become rapid and tumultuous and the water is heaped up to a great depth against the land. At the entrance of the Bay of Fundy the tide rises 8 or 9 feet, but at the head the rise at spring-tides is more than 70 feet, the greatest tidal range known. The highest spring-tide at Cardiff docks rises 42 feet, and the lowest neap-tide 20 feet, while at the mouth of the Bristol Channel the rise of spring-tide is only about 10 feet. The tidal wave rushes up some rivers with great violence, forming a *bore* or wall of foaming water stretching right across the stream, and often producing much damage to shipping in such rivers as the Amazon and Yang-tse-kiang. A tidal current sweeping through a narrow irregular channel gives rise to eddies or whirlpools sometimes of great size, like that of the Maelström in the Lofotens.

Seiches.—A slight periodic rise and fall in the water observed in lakes has sometimes been mistakenly described as a tidal effect, though its period has no relation to that of the Moon. Recent investigations show that water contained in a depression or basin shut off from the ocean may be displaced from one end or from one side to the other by various causes, such as a sudden change of atmospheric pressure, or the action of wind driving the surface water before it, and tilting the layers of water at different temperatures (see Fig. 37). From whatever cause such a displacement occurs, the body of displaced water tends to swing back like a pendulum and to become displaced to a nearly equal degree on the other side. Such a to-and-fro movement, once started, goes on with a period depending on the size of the basin until it is reduced by friction and disappears. To such a surging movement the name *Seiche* was originally given on the Lake of Geneva. As a rule seiches can only be detected by the use of self-recording instruments showing changes of level in the water surface. The seiche in Lake Erie, which is 240 miles long, has been found to have a period of 15 hours, while a seiche with a period of only 14 seconds has been found in a pond 100 yards long.

Properties of Water.—In order to understand the action of solar energy on the hydrosphere, we must know something of its composition and physical properties. The hydrosphere is composed almost entirely (about 96·5 per cent.) of water, and the total amount of this substance which exists upon the Earth is estimated at about 335 million cubic miles, or 1,500,000 million million tons. The mass of the hydrosphere is thus about 300 times as great as that of the atmosphere, but its volume is at least 100 times less. Pure water is a chemical compound of oxygen and hydrogen united together in the proportion of one-ninth hydrogen and eight-ninths oxygen by mass. Intense heat, the action of some heated metals, or the passage of an electric current, can separate the constituents, giving to water in some rare circumstances the character of an explosive. The student should read again pp. 45-48. Water, on account of its singularly high specific heat and latent heat, is better fitted than any other fluid for the part it plays in transmitting and regulating energy in Nature. Water is capable of dissolving all natural substances, although some, such as glass or silica, are taken up in minute proportions. Natural water is consequently never pure; even when perfectly clear it always contains various gases and solids in solution.

River-water contains salts of many kinds in solution derived from the surface over which it flows. The amount of dissolved solids in river-water may vary from about 2 grains in the gallon where a river flows over granite rocks, to more than 50 grains per gallon where the streams traverse a limestone country; the average salinity of river-water is about 12 grains per gallon or 0·18 parts in 1,000. The composition of the dissolved solids is different for each river on account of the different rocks traversed, but the following table gives the composition of 100 parts by weight of the dissolved salts of an average sample of river or lake water. The large proportion of carbonates and of silica and the small proportion of common salt (sodium chloride) present are characteristic.

SALTS OF RIVER-WATER

Calcium Carbonate	42·90	Carbonates =57·70
Magnesium Carbonate	14·80	
Silica	9·90	
Calcium Sulphate	4·50	Sulphates =11·40
Sodium Sulphate	4·20	
Potassium Sulphate	2·70	
Sodium Nitrate	3·50	
Sodium Chloride	2·20	
Iron Oxide and Alumina	3·60	
Other Salts	1·30	
Organic substances	10·40	
Total	100·00	

Sea-water.—The water of the ocean contains nearly 200 times as much dissolved solids as the water of rivers. Sea-water, indeed, is at once recognised by taste as *salt*, while river-water is pronounced *fresh*. Although the salinity of sea-water varies from place to place and from time to time within certain narrow limits, the composition of the dissolved solids remains almost the same everywhere. In other words, water collected in any part of the great oceans, and boiled down with suitable precautions so as to leave the solids behind, yields "salt" of almost exactly the same composition which is shown in the following table. The only exception which has been proved to this statement is that at great depths there is a slightly greater proportion of calcium or magnesium carbonate than near the surface. It is remarkable that more than three-quarters of the whole is made up of common salt, while the proportions of carbonates and of silica are very minute. Silica in carefully filtered sea-water never appears to exceed 1 part in 250,000, or 0·0004 per cent. The proportion of sulphates is nearly the same as in the salts of river-water. While sea-water probably retains in solution salts derived from the primeval atmosphere, it is evident that some agent must be at work withdrawing silica and carbonates from river-water as it enters the sea. That agency is known to be the power of living creatures—plants and animals—to make themselves shells or skeletons of silica or of calcium carbonate which they withdraw from the water. Sea-water is slightly alkaline, probably on account of its containing bicarbonates in solution. It dissolves carbonate of lime, especially when subjected to great pressure.

SALTS OF SEA-WATER

Sodium Chloride	77·70	
Magnesium Chloride	10·80	
Magnesium Sulphate	4·70	Sulphates = 10·80
Calcium Sulphate	3·60	
Potassium Sulphate	2·50	
Calcium and Magnesium Carbonate	0·30	
Magnesium Bromide	0·20	
Other Salts	0·20	
Total	100·00	

Salinity.—The salinity of sea-water is the amount of dissolved salts contained in 1,000 parts. One thousand lbs. of average sea-water contain about 35 lbs. of dissolved salts, and thus the average salinity is said to be 35 per mille. It is difficult to measure salinity directly, as some of the salts decompose when the water is boiled down. The density of sea-water, however, depends on its temperature and on the salinity, so that if the density is always measured at the same standard temperature, or corrected to it, the differences of density are due to differences of salinity alone. For example, if a bottle contains exactly 1,000 grains of pure water at the temperature of 60° F. it would contain 1,013 grains of sea-water which held 17·5 per mille of salts in solution, or 1,026 grains of water holding 35 per mille of salts. Density (specific gravity) is measured most easily by means of a delicate hydrometer, but most accurately by weighing a carefully measured portion of the water. The standard temperature to which density of sea-water is calculated is usually 32° F. or 60° F. in English-speaking countries, and 0° C. or 17·5° C. on the continent of Europe. As the composition of the salts of ocean water is practically constant the salinity may also be ascertained very accurately by measuring the amount of one constituent present, hence it is usual to measure by titration the total amount of chlorine present in a measured sample of water, and from this the salinity can be readily calculated. The density at 60° F. corresponding to various degrees of salinity and chlorine contents is as follows:—

Salinity	0·0	10·0	20·0	30·0	32·5	35·0	37·5	40·0
Density	1·0000	1·0058	1·0138	1·0220	1·0240	1·0260	1·0280	1·0300
Chlorine	0·00	5·54	11·09	16·65	18·04	19·43	20·90	22·20

Salinity of the Ocean.—As a rule the surface water of the ocean is salter than that lying beneath, the fresher water below being denser in its position, because its temperature is much lower and the pressure upon it greater. In those parts of the ocean where the rainfall is heavy the surface water is always being freshened, and its salinity is consequently lowered. The map (Plate VIII.) shows the freshened regions by a lighter tint of pink, the figures referring to the density. There is one band of comparatively fresh water in the rainy equatorial region of each ocean, and fresh zones around the melting ice of the Arctic and Antarctic coasts. Seas and ocean shores situated in regions of great rainfall, or receiving large rivers, are also usually fresher than the general surface of the ocean. The saltest water occurs in the regions of greatest evaporation and least rainfall, pre-eminently the Mediterranean and Red Sea, and in the trade-wind regions of the open oceans. The track of fresher water along the west coast of Africa and of South America is probably produced by upwelling in consequence of off-shore winds (pp. 194, 195). The way in which the very salt water extends close to shore along the coast of South America, between the mouths of the rivers Amazon and La Plata, is accounted for by the westward trade-wind drift of surface water. All the salts dissolved and invisible in the whole ocean would suffice to form a solid crust about 170 feet thick over the entire sea surface.

Absorbed Gases in Sea-water.—All atmospheric gases are to some extent dissolved by sea-water. The amount absorbed depends conjointly on the pressure of the gas (being greater as the pressure is greater), the temperature of the water (being greater as the temperature is lower), and the nature of the gas itself. Under the same pressure oxygen is nearly twice as soluble in water as nitrogen; but nitrogen exerts on the sea surface four-fifths, and oxygen only one-fifth, of the whole atmospheric pressure; thus sea-water in contact with air absorbs twice as much nitrogen as oxygen. Still, the proportion of oxygen in the air which is breathed in the water by sea creatures is twice as great as that in the atmosphere. At the average pressure and 32° F., 100 parts of water by volume absorb from air 1·56 parts of nitrogen and 0·82 of oxygen; at 70° F. the quantities absorbed are 1·00 part of nitrogen and 0·52 of oxygen, and so on in inverse proportion to the temperature. The amount of absorbed nitrogen in sea-water does not change after it has sunk below the surface; thus by finding how much nitrogen is dissolved in any part of the ocean one can calculate the temperature the water originally had at the surface, and also the amount of oxygen which must have been absorbed at the same time. The creatures living in the sea, and dead animals and plants decaying, use up oxygen, so that the full quantity which was absorbed is hardly ever found in deep water. If any part of the ocean were quite stagnant, and never renewed from the surface, the dissolved oxygen would in time become exhausted. The chemists of deep-sea expeditions have never found a sample of ocean-water free from oxygen, and this shows that all parts of the ocean are moving, however slowly. The deepest layers of the Black Sea, however, are so nearly stagnant that the water contains little dissolved oxygen, but a large quantity of sulphuretted hydrogen, and no animal life is possible there. Very little carbonic acid is absorbed from the air, on account of the small proportion of that gas in the atmosphere; but the oxygen, when used up as described above, is changed in great part into carbonic acid, which remains in the sea-water chemically combined with the carbonates.

Pressure and Sea-water.—Professor P. G. Tait found by experiment that sea-water is very slightly compressed by its own weight. Under the surface the pressure increases about 1 ton per square inch for every mile of depth. At the bottom of the deepest part of the ocean the vast pile of water exerts a pressure more than 500 times that of the atmosphere on the surface, or about 4 tons to the square inch. At this depth 11,000 cubic feet of sea-level air would be squeezed into 22 cubic feet; but 11,000 cubic feet of sea-water would only be reduced to about 10,000 cubic feet, the density being only slightly increased. If sea-water were absolutely incompressible the oceans would be about 200 feet deeper than they actually are. Sea-water is perfectly elastic. When pressure is removed from a portion it returns at once to its original volume.

Heat and Sea-water.—When sea-water is warmed it expands, steadily diminishing in density as the temperature rises. The specific heat is less than that of fresh water, for while 100 units of heat are needed to raise 100 lbs. of pure water from 32° to 33°, Professor Thoulet has shown that 93·5 units can raise the temperature of 100 lbs. of sea-water (density 1·0260) through the same range. Sea-water conducts heat better than fresh water, hence surface heat penetrates to a greater depth in the sea than in a deep lake in the same time. In hot regions with bright sunshine, the density of surface water is increased by evaporation to a greater degree than it is reduced by expansion from rise of temperature. In this way sea-water may be concentrated so much as to sink to the bottom, carrying heat with it. When heat is removed from sea-water, *i.e.* when it is cooled down, its density increases steadily, for its maximum density occurs below the freezing point. The chilled surface layer in contact with a very cold atmosphere always sinks, unless it is much fresher than the lower layers, which only happens in polar regions or near shore. Sea-water freezes about 28° F., or at a temperature 4° lower than fresh water, and in the process of freezing most of the salts separate out, so that the ice formed is nearly fresh, while the water yielding it is left much salter. All the salts are not excluded equally, the ice retaining a larger proportion of sulphates than of chlorides. Sea-water ice is soft and spongy, full of cavities containing residues of unfrozen brine, and unless it has been raised above the sea and the brine drained off the water it yields on melting is bitter and unwholesome.

Circulation of Deep Fresh Lakes.—When the Sun shines on a deep lake in the temperate zone in summer the upper layer of water is warmed, and expanding maintains its position, heat being passed on to the lower layers by the slow process of conduction. There is no tendency to transmit the heat by descending warm dense currents as in the sea. When winter sets in, the surface water cools rapidly by radiation, and contracting, it becomes denser and sinks, allowing warmer water from beneath to take its place. This process goes on just as in the sea, until the lake cools down to 39° F., but at that temperature fresh water attains its maximum density, and the similarity to the cooling of the sea ceases. Further cooling of the upper layer makes the water expand, and therefore it remains at the surface until the temperature falls to 32°, when it solidifies to form a sheet of ice. Ice is not formed as long as any of the water in the lake is warmer than 39°. The heat from the water under the ice is conducted upward very slowly, so that the whole mass of water can only become solid in very shallow lakes during a very long and severe winter. A deep fresh-water lake in a region where the summers are warm is rarely altogether cooled down below 39° during winter, unless the season is very severe, hence the common observation that deep lakes do not freeze. In calm weather the upper five fathoms of water may be affected by the diurnal range of air temperature between day and night, but the annual change of temperature between summer and winter exerts some influence to a depth of from 50 to 80 fathoms. Beneath that depth the temperature remains unchanged all the year round at 39°. A steady wind blowing in the direction of the length of a long narrow lake may, however, mix the water so thoroughly that the temperature becomes uniform from surface to bottom at any season and temperatures much lower than 39° may occur, even at great depths.

Phenomena of Sea-lochs.—Fjords or sea-lochs are miniature enclosed seas of great depth, surrounded on all sides but one by land, and barred off from the deep sea outside by a sill rising to within a few fathoms of the surface, as shown in Fig. 57. The lochs are filled with sea-water much freshened on the surface by numerous small mountain torrents, but scarcely less salt at the bottom than the open sea. When the weather is calm the surface temperature is greatly raised in summer, but at the bottom, which is cut off from tidal influence, the temperature continues to fall steadily, and comes to a minimum when the surface is warmest. As winter advances the surface cools rapidly, and since the water is comparatively fresh it continues, in spite of its increasing density, to float on the warmer sea-water below, and sometimes freezes, while at a depth of a few fathoms the temperature of the salt water may be more than 45°. The heat of summer is conducted downward so slowly that the highest temperature of the year is reached at the bottom when the surface is at its coldest in January or February; the seasons at the bottom of Upper Loch Fyne or Loch Goil, for example, being six months behind those at the surface. In the far deeper basins of the fjords of Norway seasonal changes of temperature penetrate to about 200 fathoms, but no farther.

River and Sea-water.—When a large swift river flows directly into the sea its water spreads out over the surface for many miles, floating on the salt water, which it freshens superficially. The form of the fresh stream may often be traced by the contrast of its colour with the clear blue of the ocean. Off the mouths of the Amazon and the Orinoco, for example, muddy fresh water is found floating on the surface of the sea several hundred miles from land. The Sun's heat rapidly evaporates the floating fresh water, and salt from below diffuses up and increases its density, thus enabling it to mix with the mass of the ocean, a process assisted by wind and waves. When rivers flow directly into a sea affected by tides it may happen that the current of fresh water is only slackened, but not reversed, by the rising tide. In the Spey, which is the swiftest river in Britain, salt sea-water is forced, like a dense fluid wedge, for a considerable distance up the bed of the river by the rising tide, and lifts the fresh stream to a higher level, so that perfectly fresh water is found on the surface, separated by a brackish layer a foot or two thick from the salt water below. The salt wedge is withdrawn by the ebb-tide, and the river current resumes its rapid flow to the sea. Rivers which enter the sea directly have little influence on the salinity and temperature of the deeper layers of sea-water.

Estuaries and Firths. — In the La Plata, the Thames, the Severn, the Forth, the Tay, the Garonne, and other rivers where the fresh water meets the sea gradually in a narrow inlet, the wedge-like action of the salt water at high tide is scarcely perceptible. The effect of the tidal currents sweeping to and fro in the funnel-shaped channel is to mix the river and sea-water together as if they were being shaken in a bottle. In a shallow inlet like the Thames or the Firth of Tay, where the river is large, the water is found to grow rapidly salter from river to sea, the surface being much fresher than the lower layers, and the change of salinity between high and low tide is very marked. This form of river entrance is appropriately called an *Estuary*. When, however, the inlet is very large compared with the river, and when there is no bar at the opening, the estuarine character is only shown at the upper end. In the Firth of Forth, for example, the landward half is an estuary, but in the seaward half the water has become more thoroughly mixed, the salinity is almost uniform from surface to bottom, and increases very gradually toward the sea. The result is that the river-water meets the sea diffused uniformly through a deep mass of water scarcely fresher than the sea itself, so that the two mix uniformly throughout the whole depth.

Temperature in River Entrances.—The temperature of a river in the temperate zone follows that of the land over which it flows, and is thus subject to considerable variations between day and night. River-water, unless it flows very rapidly, can never become colder than 32°; but in summer its temperature may be raised to a very high degree if there is little rain and strong sunshine. Rain lowers the temperature of rivers in summer, especially when it floods torrents descending from cold mountains. Such rivers are normally warmer than the sea in summer and cooler than the sea in winter. In an estuary or firth in summer the temperature is highest on the surface and in the river, diminishing at first very rapidly, but afterwards more slowly as the sea is approached. In autumn, on account of the more rapid chilling of the land, the temperature becomes nearly uniform in river, estuary, and sea, and from surface to bottom. In winter the water is coldest on the surface and in the river, growing warmer, at first rapidly, and then more gradually, toward the sea. In spring, on account of the land heating up more rapidly, the temperature becomes once more uniform throughout. Fig. 34 shows the actual distribution of temperature along the Firth of Forth, from Alloa to the sea, at four typical seasons, on the surface.

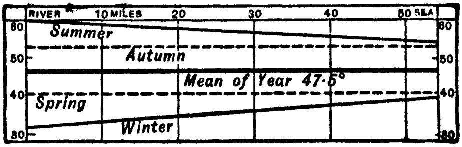

FIG. 34.—Temperature of surface water at different seasons along the middle line of the Firth of Forth. Distances from Alloa are shown in miles horizontally from left to right; temperature in degrees Fahrenheit is shown vertically.

Surface Temperature of the Ocean.—The isothermal lines on the ocean in Plate XV. represent the average temperature of the surface water for the year. Although more easily heated than fresh water, the sea surface has a less range of temperature than that of fresh lakes. This results in part from the greater clearness of sea-water, in part from its distance from heated land. The average temperature of the surface of the open ocean varies less than 1° between day and night, but between summer and winter there is a range of from 5° to 10°. Along a line drawn from Newfoundland to Iceland, the annual change of temperature between the coldest month, February, and the hottest month, August, is as much as 20°; but this is due less to the heating and cooling of water than to a seasonal displacement of warm and cold currents. In the tropical zone the sea surface has a temperature higher than 80° for the whole year. This zone of hot water is widest in the Indian Ocean and narrowest in the Atlantic; and in the Atlantic and Pacific it is wider on the western than on the eastern shores. The temperature falls very uniformly toward the south, reaching 40° F. about latitude 48° S. south of Africa, but not until latitude 58° S. south of Cape Horn. In the Southern Ocean there is practically no annual change of temperature, the water growing steadily colder toward the Antarctic ice at all seasons. Toward the north the ocean grows cooler more gradually, 40° being found in summer only in the Arctic Sea, but in winter between New York and Lofoten Islands, and between Japan and Alaska. As a general rule the sea surface on the west coasts of the southern continents is colder, and on the west coasts of the northern continents warmer, than on the east coasts in the same latitudes. The northern half of each ocean is also warmer than the southern half at all seasons. Enclosed tropical seas have the highest temperature of any water surfaces in the world. In the Red Sea readings of from 90° to 100° F. have been reported.

Polar Seas.—The Arctic Sea, lying in the coldest region of the globe, is completely covered with drifting ice, measuring from 2 to 14 feet in thickness, and only partially dissipated in summer. Ice formed along the shore-line, remaining attached to the land as a flat shelf, is termed the *ice-foot*. In summer, on the edge of the Arctic Sea, ice-islands, or *floes*, some of which have been seen 60 miles long, drift away with the wind. Open lanes of water appear in summer in all parts of the Arctic Sea, and even in winter they are formed by the cracking of the floating ice, while in other places the ice is packed high in pressure ridges. Sir George Nares, in 1874, found the ice in what he called the Palæocrystic Sea, north of Greenland, more than 150 feet thick. Dr. Nansen, during the drift of the *Fram* in 1893-96, saw no such thick and ancient floes, and he believes that they can only be formed off coasts against which the ice is drifted. The water in which the floes float has the temperature of melting sea ice (about 28°), and the lower layers are usually considerably warmer. Indeed, in polar regions there are often alternate layers of cold and warm water, one above another, the greater salinity of the warmer water making its density greater than the colder but fresher water above. A temperature curve of such a region ("Atlantic 71° N. lat.") is shown in Fig. 35. The ends of great glaciers or ice-sheets reaching to the sea break off in the water and float away in summer as *icebergs*. In the Arctic regions the icebergs are lofty pinnacled masses often resembling cathedrals or castles several hundred feet in height, with a covering of dazzlingly white snow, but showing the true ice-colour of intense blue in their cracks and caves. Lofty as these icebergs are, we know that as ice has a density of about 0·9, only one-ninth of its volume floats above water. The flat-topped ice-islands of the Antarctic have been shown to originate by the breaking off of portions of the floating ice-barrier which lies between Victoria Land and King Edward Land, and the late Captain Scott has shown that this is largely composed of compacted snow.

Temperature of Ocean Depths.—The hot surface water in the tropical zone is merely a film covering a vast depth of cold water. Even although the surface is at 70° or 80°, a temperature of 40° or less is found at a depth of from 300 to 400 fathoms in almost all parts of the ocean. The fall of temperature is consequently very rapid from the surface down to 400 fathoms in the tropics; but much less abrupt in the cooler regions to the north and south. Below 400 fathoms the fall of temperature to the bottom is everywhere very slight and gradual (Curve, "Pacific 5° N. lat.," Fig. 35), and no matter how great the depth may be the bottom temperature of the open ocean remains near the freezing point of fresh water. Five-sixths of the mass of the ocean has a temperature under 40° F., so that taken as a whole the hydrosphere is a body of cold water, its average temperature being probably about 38° or 39°. The prevailing low temperature of the hydrosphere is explained mainly by the melting ice surrounding the Antarctic continent and in free communication with the open ocean, round the whole circumference of the Antarctic Circle. The Arctic Sea ice produces a much smaller effect, as it is shut off from the ocean except at the narrow Bering Strait in the Pacific, and in the North Atlantic, where the cooling is marked only in the cold current of the western side. The surface drift of warm salt water carried into the Southern Ocean from the north grows gradually cooler and therefore denser, and sinks about latitude 50° S. About this latitude also the comparatively fresh and cold water drifting northward from the Antarctic regions grows salter and sinks on account of the consequent increase of density. The sinking water appears to be drawn back by slow and massive movements to north and south, thus maintaining the circulation of the ocean to its greatest depths.

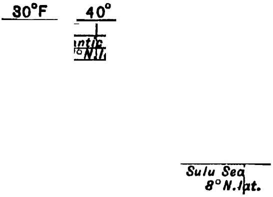

FIG. 35.—Curves of vertical distribution of Temperature in the Ocean. Temperature is shown along the top; depth down the side.

Temperature in Enclosed Seas.—Except in polar regions the temperature at the bottom of the deep ocean is much lower than the average winter temperature of the air at sea-level; but this is not the case for deep enclosed seas. The common form of enclosed seas is that of a basin, often descending to oceanic depths, but barred off from the ocean by a sill. The Red Sea, for example, is separated from the Indian Ocean at the Strait of Bab-el-Mandeb by a sill rising to within 200 fathoms of the surface, while it attains a depth of 1,200 fathoms near the centre, and the Indian Ocean in the Gulf of Aden is still deeper. In the Red Sea the temperature at the surface varies from over 85° in summer to about 70° in winter. At the hottest season the rate of cooling is comparatively rapid to a depth of 200 fathoms, where the temperature is 70°, and from that level right down to the bottom the temperature remains uniform all the year through. The basin of the Red Sea is thus filled up to the lip with uniformly warm water, whereas, as shown in Fig. 36, the water of the Indian Ocean, nearer the equator, and with the same surface temperature, sinks to 70° at about 200 fathoms, and falls as low as 37° at 1,200, where it is prevented from entering the Red Sea basin by the ridge. The surface water in the Red Sea is densest when its temperature is lowest in winter, and the dense layers at 70° temperature sink to the bottom, so that the whole basin below the level of the barrier assumes and maintains the lowest average winter temperature

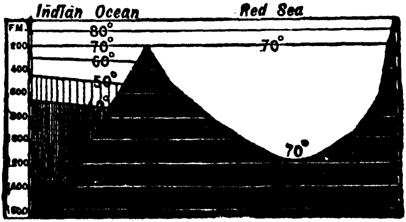

FIG. 36.—Temperature Section of the Red Sea and Indian Ocean; showing the action of a barrier in separating bodies of water at different temperatures. The shading is darker as the temperature is lower. Not drawn to scale.

of the air above. The hotter water in summer being less dense on account of its expansion, though it contains more salt, remains floating on the surface, and its heat passes down only by the slow process of conduction. The Mediterranean furnishes another instance of the same distribution of temperature. The sill separating its basin from the Atlantic is 190 fathoms below the surface, and the water on it is at 55°, a temperature which prevails to the bottom of the Mediterranean, while in the Atlantic the temperature falls as low as 35° at the same depth.

Circulation of Seas by Concentration.—The great evaporation in the Red Sea raises the density of its surface water (at 60° F.) to 1·0300, and the salinity is 40 per mille. The level of the sea is lowered by evaporation to the extent of from 10 to 25 feet a year, and a surface current of the fresher but equally hot water of the Indian Ocean is consequently always pouring in. If there were no return current of dense salt water, it is calculated that the Red Sea would become a mass of solid salt in less than 2,000 years. Since there is no perceptible change in its salinity, it is certain that a deep undercurrent of salt water passes out through the Strait of Bab-el-Mandeb sufficient to carry back to the Indian Ocean all the salt received from it. The circulation of the Mediterranean is carried on in the same way, as the rainfall it receives is only equal to about one-quarter of the evaporation from its surface, and its water, although of higher salinity than the neighbouring Atlantic, is not growing salter. The outflowing current through the Strait of Gibraltar underneath the inflowing fresher current has been observed, and the deep water of the Atlantic for a long distance to the west and north is perceptibly warmed and increased in saltness by the outflow.

Circulation of Seas by Dilution.—The Black Sea is a deep basin cut off from the Mediterranean by the shallow Bosphorus, the Sea of Marmora, and the Dardanelles. This sea contains only about 20 per mille of salts, its waters being very much freshened by the Don, Danube, and other great rivers which flow into it, supplying more water than is removed by evaporation, and raising its level about 2 feet higher than that of the Mediterranean. A steady surface outflow of brackish water from the Black Sea consequently sets through the Bosphorus; but a slower stream of salt Mediterranean water must find its way along the bottom into the Black Sea, as that sea is not growing fresher. The cause of the undercurrent of salt water between seas of different salinity is that a column of salt water exerts the same pressure as a column of fresh water higher in proportion to the difference of salinity. But (p. 24) water cannot stand at a higher level beside water at a lower level, and the fresher water pours over the surface of the salter column, upon which the pressure is thereby increased and the undercurrent is produced in order to equalise matters. As long as the supply of fresh water is kept up there can be no equality, and thus the circulation continues. The Baltic Sea has a somewhat similar circulation, though in this case it is complicated by the effects of wind.

Wind-waves.—Part of the water surface yields to the stress of wind striking it obliquely, and is depressed, thereby ridging up the neighbouring portions and originating a wave, the form of which advances as a line of rollers before the wind. Only the form advances, for while the particles of water in the crest of a wave are moving rapidly forward, those in the trough move back to almost exactly the same extent. Thus rollers merely lift and lower the vessels that float upon them. Water being an elastic substance continues to swing up and down as a swell after the wind which produced the motion has died away, just as a pendulum continues to swing after the hand setting it in motion is withdrawn. Waves may be transmitted from a great distance, and as wind is always blowing somewhere, the surface of the ocean is never quite at rest. When a wave enters gradually shallowing water the lower part is retarded by friction, and the upper part sweeps forward more rapidly. The wave becomes steeper and shorter, and finally the top curves over in a hollow sheet of clear water, which breaks with a roar into foam and spray, the roller becoming a breaker. The highest wind-waves that have been measured have an amplitude of only 50 feet from trough to crest, and a length of about a quarter of a mile between successive crests. Earthquakes raise waves of much greater height and destructive power than either tide or wind. The wave form travels over the sea at a rate depending on the size of the wave and the depth of the water, the maximum speed being about 80 miles an hour. At the depth of 100 fathoms the greatest waves produce a movement too slight, as a rule, to move anything but the finest mud, and probably wave-motion never penetrates to as great a depth as 500 fathoms.

Circulation of Water by Wind.—Apart from producing waves, the wind slips the top layer of water before it as one might slip a card from the top of a pack, and although it can act only on a very thin film a new surface is constantly exposed, and a steady breeze causes a great surface drift. Dr. J. Aitken appears to have been the first to point out the importance of this action in disturbing the deeper layers of water. Sir John Murray, by a series of temperature observations on Loch Ness, showed that wind acting in this manner on the surface of a deep lake could completely alter the distribution of the water. The explanation of his observations seems to be as follows: On a calm summer day this lake contains a surface layer about 15 fathoms deep, the temperature of which is from 60° to 50°, floating upon 100 fathoms of water, the temperature of which is from 50° to 40°. When strong wind blows steadily along the length of the lake from A to B (Fig. 37) the surface water is driven toward B, where the wind heaps it up, but the greater pressure of the heaped-up water causes the lower layers at B to move off toward A, and thus the whole end of the lake-basin at B is filled with the warm water that had been resting on the surface, while the cold water formerly filling the depths rises against the shore at A, as represented by the arrows. If the wind lasts long enough the water will be thoroughly mixed, and the temperature made uniform throughout. It has been shown, by the author for sea-lochs and by Sir John Murray for deep fresh-water lakes where there is an abrupt change of temperature at a certain depth, that the circulation set up by wind is like that in Fig. 37 for the upper layers only, and that there is a simultaneous circulation in the opposite direction in the lower layer.

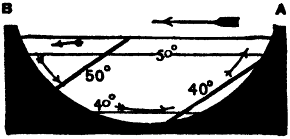

FIG. 37.—Circulation of water by wind. The light lines and figures show distribution of temperature before, and the dark lines and figures distribution of temperature after, the wind has been blowing in the direction of the long arrow.

Effect of On-shore and Off-shore Winds. — Bathers know that in summer the sea is colder when the wind is blowing from the land than when it is blowing from the sea. The reason is that the wind blowing from the sea (an "on-shore" wind) drives the surface water, which has been heated over a wide area, in toward the shore, on which warm water becomes banked up to a considerable depth, displacing the cold lower water, which slips seaward as an undercurrent (B, Fig. 37). During a prevailing sea-wind the water along the shore assumes what may thus be called an on-shore condition, just as by blowing steadily across a milk dish one might drive the cream to one side, and even blow it up on the shelving lip, completely displacing the milk on that shallow coast. A wind from the land in like manner drives the warm surface water seaward, and colder water from a greater depth wells up to take its place (A, Fig. 37), this being characteristic of an off-shore condition. This enables us to understand how the permanent winds of the Earth which blow steadily off shore (like the trade winds from the west coast of Africa and South America) cause cold water to well up from great depths. The upwelling off the coast of south-western Africa and off the coast of Morocco explains the exceptionally low sea surface and air temperatures observed in these neighbourhoods, and similar conditions are found on the west coasts of Australia and South America. Where the prevailing winds blow against the land, as on the north-east of South America into the Caribbean Sea, and toward western Europe, the sea assumes a permanent on-shore condition, the warm surface water from the tropics being piled up against the land, while the colder deep water natural to the locality slips away seaward. The effect of the prevailing winds of the world is to set up a general skimming of the ocean from the equator poleward, sweeping the warm surface water away to one side and allowing cold water from the depths to rise up, completing the vertical circulation.

Wind and Ocean Currents.—In a strong gale the wind blows off the crests of the waves in spray or spin-drift, and even a moderate breeze sweeps forward a thin layer of surface water over the ridged surface of the sea, giving rise to what is called a surface drift. The currents of the Indian Ocean and of the sea off the west coast of Central America change twice a year with the changing of the monsoons, and it is recognised that these currents are produced solely by the wind. Ocean currents are very different from surface drift. They are usually tracts of the sea surface, the water of which flows strongly in a definite direction, passing through the rest of the sea without appreciable mixing, as a river runs through a meadow. Some of these ocean rivers flow in a constant direction at the rate of nearly 4 miles an hour; thus it is important to sailors to map out the ocean so that they may avoid or take advantage of the currents in making a passage. Solar energy in one form or another is undoubtedly the power that keeps the whole system of oceanic circulation in motion, and the rotation of the Earth together with the form of the coast-lines of the continents direct the flow of currents. Sun-power acts on the hydrosphere (*a*) by raising the temperature in the tropical regions far above that in the polar zones, thus causing expansion and altering the level; (*b*) by causing great evaporation in the tropical regions, great rainfall in equatorial regions, and moderate rainfall in the temperate zone, thus altering both level and density; (*c*) by setting up the whole system of winds. Some difference of opinion exists as to the chief cause of oceanic movement, but it is usually allowed that the most powerful is the wind. All three, however, act together and each modifies the other. If the student compares the map of ocean currents (Plate XVIII.) with those of temperature, of salinity, and of prevailing winds (Plates XV., VIII., V., VI.), he will see that the currents circulate in the same way as the winds and around nearly the same centres, which lie close to the regions of maximum sea-temperature and salinity. All ocean currents are more or less irregular in direction and speed; they usually flow as nearly parallel streams separated by spaces of still water, and vary in position and strength, as the winds do, with the time of the year. It is not impossible that two currents moving in opposite directions may penetrate each other without the complete mixture of the component threads of moving water. Plate XVIII. should be referred to in reading the following paragraphs.

Equatorial Currents of the Atlantic.—The trade winds blowing from the west coast of Africa drive the surface water before them in rapid currents. The *North Equatorial Current*, sweeping along the north-west coast of Africa past the Canary Islands, turns toward the west about the latitude of Cape Verde, and while part of it is driven by the north-east trade winds into the Caribbean Sea, most of the current sweeps north-westward, turning to the right, outside the West Indies, toward the coast of North America, The *South Equatorial Current*, originating in the *Benguela Current* of cool water, flows northward at first. In the latitude of the Congo it sweeps westward across the ocean and divides into two branches off the wedge-shaped front of South America. One branch turns to the left southward along the coast, and is known as the Brazil Current; and getting within reach of the brave west winds, it is drifted east again, part of it rejoining the Benguela Current. The other branch continues on its westerly direction and is driven northward by the south-east trades, most of it flowing into the Caribbean Sea. Along the north-east coast of South America there is a heaping up of water, produced by the convergence of the two great equatorial currents, and this does not appear to be fully compensated for by vertical circulation. Some of the banked-up water escapes eastward on the surface along the rainy zone of the equatorial calms, forming a narrow but very rapid counter-current between the west-flowing North and South Equatorials. Near the coast of Africa this *Counter Equatorial Current*, consisting of extremely hot water of slight salinity, and known as the *Guinea Current*, sweeps along the north shore of the Gulf of Guinea, and is deflected southward by the coast to rejoin the South Equatorial.

The Gulf Stream and Gulf Stream Drift.—The level of the Caribbean Sea and Gulf of Mexico is raised considerably by the hot surface water continually pouring in from the south-east. Off the mouth of the Mississippi it is said to be about 3 feet higher than off New York. The *Gulf Stream* forced out of this reservoir through the Strait of Florida is a river of salt and very warm water (surface temperature 81°), 50 miles wide, 350 fathoms deep, and flowing at the rate of 5 miles an hour. On emerging from the strait it is swept to the north close along the American coast by the branch of the North Equatorial Current, which has passed outside the West

Indies and through the Bahamas. The Gulf Stream sweeps the bottom clear of mud not only in the strait but for a considerable distance northward. As it flows on, it grows wider and shallower; off Cape Hatteras it turns to the right away from the American coast and coming within the range of the prevailing south-westerly winds, it merges in the general surface drift of the North Atlantic, spreading out like a fan and growing cooler as it flows. The Gulf Stream drift passes to the south of the Grand Banks of Newfoundland with a velocity of about 1½ miles per hour, and its rate gradually diminishes to about 4 miles a day in the general North Atlantic drift. This drift of comparatively warm water forks into three, diverging toward the coast of Spain, the British Islands, Norway, and the south-eastern coast of Iceland, stranding driftwood on that treeless island. The surface water of the tropics is thus being steadily poured into the temperate North Atlantic, where it drives the cold deep water in an undercurrent toward the south, and gives rise to the highest temperature at great depths found in any part of the open ocean. The temperature of 40° occurs as deep as 900 fathoms off the west of Scotland, and seldom deeper than 300 fathoms in the tropics. This is the source which supplies the southwest wind with heat and moisture to modify the climate of western Europe.

Polar Currents of the Atlantic.—Careful study of the drifting of ice-floes in the Arctic Sea gives some ground for believing that a current sets straight across from near the New Siberian Islands on the coast of Asia toward Arctic North America. Dr. Nansen in the *Fram* set out in 1893, and his vessel, which was frozen in off the New Siberian Islands, was drifted slowly across to a point north of Spitsbergen in 1896, having reached 86° N. on the way. A cold current, carrying icebergs in summer, when the frozen sea breaks up, flows south from the Arctic Sea between Spitsbergen and Greenland. It passes along the north coast of Iceland, where it strands driftwood from the Siberian rivers, and as the East Greenland Current flows more rapidly, under the influence of prevailing north-easterly winds, along the east coast of Greenland, causing that side of the great ice-covered peninsula to be much colder and less accessible than the west. The Labrador Current is a more important cold stream, driven also by the northerly winds, and flowing southward along the west side of Baffin Bay, past the coasts of Labrador and Newfoundland. It meets the northern edge of the Gulf Stream Drift off the Grand Banks of Newfoundland. It is probable that this encounter led to the formation of the Banks, for the icebergs carried by the Labrador Current are melted on entering the Gulf Stream Drift, and drop the stones and mud which were frozen up in them. The mingling of cold and warm currents undoubtedly produces the fogs for which this region is famous. Being comparatively fresh, the density of the cold Labrador Current is not greater than that of the Gulf Stream, by which it appears to be deflected along the coast of North America, where it is known as the Cold Wall. It disappears from the surface off Cape Hatteras, having partly mixed with the Gulf Stream and in part sunk under the less dense because warmer water. It is probable that the cold current cuts horizontally through the Gulf Stream, like a paper-cutter through the leaves of a book, and mixes with the mass of the Atlantic water. The limits reached by icebergs drifted from the north and south are shown on Plate XVIII., illustrating how the warm currents off northern Europe keep the sea there clear of this danger. The cool water of the Benguela Current is partly supplied by upwelling from beneath, but the steady flow of the current is maintained by cold streams sweeping north-eastward from the Antarctic regions.

Circulation of the Atlantic.—The Gulf Stream is often spoken of as if it were a phenomenon by itself;

but it is really only part of a great system of surface circulation, the water whirling as if stirred in the direction of the hands of a watch in the northern Atlantic, and as if stirred in the opposite direction in the southern part of the ocean. The centre of each whirl is nearly at rest, and immense quantities of floating seaweed accumulate, especially in the North Atlantic, where the calm weed-hampered water is known as the Sargasso Sea. The deep water in the Arctic Sea was found by Dr. Nansen to be warmer than the upper layers, pointing to the circulation of warm currents from the Atlantic through it. Much of the surface water sinks off the British Islands south of the Wyville-Thomson Ridge. Over this ridge the Atlantic water streams so strongly that the bottom is swept clear of mud to the depth of 500 fathoms, and passing over the cold deep water of the Norwegian Sea, sinks below the colder but fresher surface water of the Arctic basin.

Currents of the Pacific Ocean.—The Pacific Ocean, on account of its vast extent and its remoteness from great trade routes until within recent years, has not yet been so fully studied as the Atlantic. It is known, however, that the general system of its circulation is the same, and the map should be carefully studied in order to recognise the similarities. The Bight of Panama, extending along the west coasts of Central America and of the north of South America, serves, like the Gulf of Guinea, as the starting-place of the great equatorial current system. The south-east trade wind produces the *Peru Current* as a stream of cool water raised by the off-shore winds, precisely like the Benguela Current of the Atlantic. This stream, deflected westward by the Peruvian outcurve of the coast, sweeps as a *South Equatorial Current* past the Galapagos Islands on the equator, giving them a cooler climate than any other equatorial land. Setting westward before the steady trade winds, it sends off branches to the south, which wind amongst innumerable island groups, and ultimately reunite under the influence of the brave west winds, and drift eastward to rejoin the Peru Current. The main branch of the South Equatorial Current splits at New Guinea, a small part passes through Torres Strait to the Indian Ocean, but the main body streams through the Malay Archipelago toward the Philippine Islands. Toward this goal the *North Equatorial Current* is also driven by the north-east trade wind, and as in the Atlantic, the piling up of warm surface water amongst the islands gives rise to a strong *Counter Equatorial Current*, which sets straight eastward across the Pacific, along the line of equatorial calms, into the Gulf of Panama. The South Equatorial Current streams from the South China Sea into the Indian Ocean in winter, when the north-east monsoon is blowing, and mixes with a cold current flowing south from the Japan Sea. But in summer, during the south-west monsoon, the pressure of water in the China Sea is increased by tributary currents from the Indian Ocean, and acts in many respects like the Gulf of Mexico. The extremely hot water (surface temperature 85°) escapes between Luzon and Formosa as a broad salt river. As it sweeps past the east coast of Japan, and begins to widen and thin out, the name *Kuro Siwo* or *Black Stream* is given it, from the deep colour of its clear water. The Kuro Siwo comes within reach of the prevalent south-west winds, and, like the Gulf Stream Drift, is carried at a diminishing rate eastward across the ocean, merging into a general surface drift, which washes the coast of Alaska and British Columbia. The North Pacific has its temperature increased throughout a great depth in this way. Cold currents resembling those of Greenland and Labrador, but much smaller in volume, set south from Bering Sea along the coast of Kamchatka and Sakhalin, passing between Japan and the Kuro Siwo like a cold wall.

Currents of the Indian Ocean.—The south-east trade wind blows the surface water westward off the coast of Western Australia, causing an upwelling of colder water similar to the Benguela and Peru Currents. The *South Equatorial Current* of the Indian Ocean is reinforced by affluents from that of the Pacific between Australia and Java, which give to the eastern shore of the ocean a partially on-shore character. Turning to the left as it flows west, the South Equatorial Current washes the east coast of Madagascar, and turns south in several branches, which are drifted back to the West Australian Current by the brave west winds. A strong drift of warm water passing southward along the Mozambique Channel is known as the *Agulhas Current* off the south of Africa, from the fact that the Agulhas Bank turns the bulk of the stream from its south-westward direction back to the east. A narrow stream of the Agulhas Current rounds the Cape and joins the Benguela Current in the Atlantic. In winter, when the north-east monsoon is blowing, a *North Equatorial Current* appears, eddying westward round the Bay of Bengal and Arabian Sea, and setting southward along the coast of Africa to join the Agulhas Current. At this season there is also a well-marked *Counter Equatorial Current* across the ocean from Zanzibar to Sumatra, rather to the south of the equator. During the south-west monsoon the currents in the northern part of the Indian Ocean are reversed. The Somali coast assumes an off-shore condition, with a strong upwelling of cold water, and the currents flow in eddies eastward round the Arabian Sea and Bay of Bengal in the same direction as the Counter Equatorial Current, the force of which is increased.

Currents in the Southern Ocean.—The westerly winds of the Roaring Forties carry a continuous surface drift of water in an easterly direction round the world, thus serving to mix the surface waters of the three great oceans. In many parts of the Southern Ocean slow drift currents of small volume set northward, and this is particularly the case toward the west coasts of the southern continents. Drift ice is rarely found farther north than the latitude of 40° S., but south of 45° Antarctic icebergs are very frequently met with.

Functions of the Sea.—The hydrosphere regulates the distribution of energy, acting as a great fly-wheel to the world machine. Solar energy, directly or indirectly, is the cause of all its non-tidal movements. The sea carries nearly half of the sun-heat falling in the tropical zone to higher latitudes, and from the high latitudes of the south it tempers the tropical climates of the western shores of the continents by cold updraughts. By the solution and restoration of carbonic acid it helps to maintain the uniform composition of the atmosphere, and by its comparatively slow changes of temperature it keeps up land and sea breezes and monsoons. It is an unfailing reservoir for supplying water-vapour to the atmosphere, and rain for the lakes and rivers. The smooth and level surface of the ocean allows the normal system of atmospheric circulation to be established more perfectly than is possible on the land, and so gives rise to the steady winds which dominate the climate of the whole globe. In the sea also the material brought down by rivers from the land is redistributed and worked up into new forms.

BOOKS OF REFERENCE

See end of Chapter XII.

CHAPTER XII

THE BED OF THE OCEANS

The Lithosphere.—The wide smooth expanse of the hydrosphere is apt to give one a wrong idea of the surface of the Earth by veiling the configuration of the great hollows. Serious attempts to find out the whole form of the lithosphere only began when the vast hidden region acquired commercial value as a bed for telegraph cables. Since the commencement of submarine telegraphy, accordingly, the process of taking deep-sea soundings has been rapidly perfected, and very numerous accurate measurements of depth have been made in all the oceans. During the magnificent expedition of the *Challenger* in 1872-76, many deep soundings were taken for a purely scientific purpose in parts of the oceans never likely to be visited by telegraph ships. In recent years many smaller expeditions fitted out by the British Government and by the Governments of the United States, Norway, Germany, France, Austria-Hungary, Holland, and other nations as well as private expeditions have made detailed studies of parts of the sea-bed. The form of the floor of the ocean has thus been gradually felt out point by point, and we are now able to compare the general features of the veiled part of the lithosphere with the smaller portion which is open to the light of day. If the Earth, like the Moon, had lost its hydrosphere, and could be viewed from a distance, the surface would appear to be made up of two great and roughly uniform regions, both convex, following the curvature of the globe, but one about 3 miles higher than the other. The lower and larger is composed of broad, gently undulating plains rising into gentle ridges, and broken by some abrupt peaks. It is divided into bay-like expanses by the higher region, the slopes up to which are almost everywhere steep and in places precipitous. The higher region is smaller and more diversified, rising into numerous terraced plateaus and rugged peaks. The hydrosphere entirely covers the whole of the low-lying region and the lower slopes of the higher region, only the plateaus and peaks of the latter project above the water surface and form the land. The land surface has been surveyed in some detail by the survey departments of the various governments, but the ocean depths are only known along the shores and on certain lines where soundings have been taken. The late Prince of Monaco, aided by an international committee, combined all known soundings in one great map of the oceans on which contour lines of equal depth have been drawn so as to bring out the larger features of submarine configuration.

Sea-Level.—The surface which naturally presents itself for purposes of comparison in describing the configuration of the Earth is that of the Ocean. This surface is usually considered to be level, that is to say, it is looked on as having the exact form of the geoid (p. 54) and being concentric with it. The level of the sea at any place is always varying on account of waves and tides. In constructing charts, all soundings of depth are corrected to their value for a calm sea at the average low water of spring-tides for the place in question. Heights on land are measured from a datum-level, which differs in different countries, but is usually the average height of the sea at some selected place. The heights marked on the Ordnance Survey maps of Great Britain are quite accurate with regard to the datum-level (that of mean tide at Liverpool), but are 8 inches too high compared with the average sea-level round the island, and in certain places are probably as much as 2 feet too high or too low compared with actual mean sea-level. Many reasons exist for these small permanent differences of level, such, for example, as heavy local rainfall, or evaporation, the direction of prevailing winds or currents. The greatest distortion of the sea-surface is, however, due to the mobility of water and its readiness to yield to the attraction of gravity. If the surface of the lithosphere were smooth and its interior of uniform density, this property of water would ensure a truly similar surface in the ocean. The Elevated Region projecting to unequal heights far above the general level of the Earth, and being composed of substances of different density, attracts the water by gravity towards itself, and thus disturbs the uniform action of the central force, much as the sides of a tumbler attract the contained water by cohesion and heap it up slightly at the edges. The amount of distortion in the hydrosphere is as difficult to determine as the form of the Earth itself and must be found in the same way. It was shown by the survey of India that the sea-surface is 300 feet nearer the centre of the Earth at Ceylon than it is at the Indus delta, where the attraction of the Himalayas comes into play. At other places the heaping up may be somewhat greater; but this distortion of the water surface interposes no obstacle to the movement of ships, a ship being as much a part of the ocean from the point of view of gravity as the water itself. The rocks beneath the bed of the ocean are, however, known to be of greater density than those composing continents, and therefore their attraction on the sea should to a large extent counterbalance that of the land.

Volume of Oceans and Continents.—The most logical datum-level is the mean surface of the lithosphere, the surface which would be produced if the heights were all smoothed down and the hollows filled up uniformly. An approximation to the position of this surface was first made in an estimate by Sir John Murray of the area of land and sea lying between certain limits of height and depth, and the data have since been amplified. From the areas the total volume of the land which projects above, and of the oceanic hollows which extend beneath, sea-level has been calculated. The land occupies about 55,000,000 square miles, and its average height is about 2,300 feet above sea-level, while the sea covering the remaining 141,000,000 square miles of surface has an average depth of 12,000 feet, or 2,000 fathoms. The loftiest point of the land, Mount Everest, in the Himalayas, reaches to 29,000 feet above sea-level, and the deepest parts of the Pacific Ocean descend to a depth of 31,600 feet below sea-level. The whole vertical range on the surface of the lithosphere is thus about 60,600 feet, nearly 12 miles, which is only $\frac{1}{700}$ of the Earth's diameter. The narrow crest of the Elevated Region forming the visible land has only $\frac{1}{14}$ of the volume of the ocean hollows, and thus the average level of the solid Earth evidently lies beneath the sea-surface. There are about 300,000 square miles of the Earth's surface more than 15,000 feet above sea-level, and more than 45,000,000 square miles more than 15,000 feet below sea-level; while above 24,000 feet above sea-level there are only about 8,000 square miles, and below 24,000 feet below sea-level there are at least 150,000 square miles.

Mean Sphere Level.—From Murray's figures, the position of the mean surface of the lithosphere (mean sphere level) was calculated by the author to be about 10,000 feet (1,700 fathoms) below the present sea-level; it was afterwards estimated by Professor Wagner at 7,500 feet, but more recent exploration tends toward confirming the earlier figure. If we imagine a transparent shell, similar in form to the Earth and concentric with it, to cut the slope between the elevated and depressed areas at 10,000 feet below present sea-level, the volume of all the elevations projecting above the shell would be precisely equal to the volume of all the depressions extending below it. But one-half of the area of the Earth's surface also is above mean sphere level, and one-half below. The line of mean sphere level which is traced on a map (Plate XIV.) thus serves to divide the surface of the lithosphere into a depressed and an elevated half.

Three Areas of the Lithosphere.—The depressed half of the lithosphere is called by Sir John Murray the *Abysmal Area*, all parts of which are always covered by water more than 10,000 feet deep. The upper part of the elevated half of the lithosphere forms the *Continental Area*, which is always above water, and occupies rather more than one-quarter (28 per cent.) of the surface. The remainder of the surface, measuring somewhat less than one-quarter (22 per cent.), and always covered by water less than 10,000 feet deep, is called the *Transitional Area*. The position of the coast-line or boundary between the Transitional and Continental Areas obviously depends on the volume of the hydrosphere. It is convenient for most purposes to class the Abysmal and Transitional Areas together as the Bed of the Oceans. Professor Wagner prefers to divide the Earth's surface into five areas, viz.: The *Culminating Area* (6 per cent. of the Earth's surface), over 3,280 feet above sea-level; the *Continental Plateau* (28 per cent.), extending thence down to the lower edge of the Continental Shelf, or 660 feet below sea-level; the *Continental Slope* (9 per cent.), reaching down to 7,500 feet (Wagner's mean-sphere level); the *Oceanic Plateau* (54 per cent.), to a depth of 16,400 feet; and the *Depressed Area* (3 per cent.), including all greater depths. A system of terminology for the forms of sub-oceanic relief has been prepared with equivalent expressions in English, German, and French by an International Committee, and the French terms are used on the great Monaco Map.

Elevated Half of the Lithosphere.—The elevations and depressions of the Earth, although irregular in form and distribution, are arranged with a certain rough symmetry about the poles. A small detached elevation occupying about one-twelfth of the area of the elevated half has its centre about the South Pole, and slopes down to mean sphere level not far to the north of the Antarctic circle. The surface of the northern hemisphere is as a whole more elevated than that of the southern. A great Northern Plateau, surrounding the North Pole at a distance of 2,000 miles, and broken by two connected depressions (those of the Norwegian and Arctic Seas), is the centre of a continuous mass comprising fully nine-tenths of the whole elevated half, and extending toward the south in two vast World Ridges of unequal size. In reading the following paragraphs the student should refer constantly to the map (Plate XI.), and to Plate XIV. on which the line of mean sphere level is depicted. The *Western World Ridge* stretches from 60° N., where the Polar Plateau splits, in a south-easterly direction to the equator, and thence southward, rapidly narrowing, to 60° S. The ridge, nowhere of great width, is narrowest between the Tropic of Cancer and the equator, where three small isolated depressions (the basins of the Caribbean Sea and Gulf of Mexico) nearly sever it. The crest of this ridge forms the connected continents of America. The *Eastern World Ridge* is of much greater size, and has somewhat the form of a horse-shoe, the toe to the north. The western limb rises very steeply from the depressed area, and tapers southward to a point in 40° S.; it is crowned by the continent of Africa, and marked off from the European portion by two small depressions forming the deep basins of the Mediterranean. The eastern limb, marked off from the solid mass, which is the foundation of Asia, by a great series of deep depressions (the basins of the seas of the Malay Archipelago), runs south-eastward as a comparatively narrow ridge bearing Australia, and ends at 55° S. in two great spurs from which

Tasmania and New Zealand rise. The origin of the great features of the relief of the lithosphere with the characteristic narrowing of the World Ridges to the south, and their twist toward the east, was considered by Sir George Darwin as possibly due to the action of tides (p. 71) in the still plastic crust of the Earth.

The Depressed Half of the Lithosphere or Abysmal Area, forms a hollow ring round the south polar elevation, and runs northward in the form of nearly flat-bottomed troughs between the steep slopes of the World Ridges into the great Arctic depression. It is ridged by long gentle rises and abrupt mountain-like peaks, and grooved by depressions infinitely various in size and form. Distinct hollows or basins of the Abysmal Area correspond to each ocean, and the slopes of the World Ridges rising from them usually run parallel to the shore line which bounds the various oceans (p. 173). The basins of the Pacific, Atlantic, and Indian Oceans extend southward into the Southern Ocean, which does not appear to have a separate basin. A typical section studied in conjunction with the map will impress the general form on the student's mind, although the scale of depth is necessarily exaggerated.

The Atlantic Basin, extending between the eastern edge of the Western, and the western edge of the Eastern, World Ridge, is long and comparatively narrow. It is deepest near the walls (Fig. 38), forming, in fact, two long sinuous troughs separated by the Central Rise, which reaches on the average to mean sphere level. The Azores, St. Paul Rocks near the equator, and Ascension, all spring from this rise, while the lonely islets of Tristan d'Acunha mark its southern extremity. Four great trenches, or groups of trenches, the floors of which descend to more than 3,000 fathoms below sea-level, occur symmetrically, two in each of the lateral troughs, one north and one south of the equator. In 20° N., just north of the Virgin Islands, the deepest sounding in the Atlantic was obtained, 4,561 fathoms below sea-level, or nearly 18,000 feet below mean sphere level (see Fig. 38). The Central Rise joins an east-and-west rise in the latitude of South Georgia, which separates the Atlantic troughs from the Indo-Atlantic Basin of the Southern Ocean. The depression of the Caribbean Sea, Gulf of Mexico, and Mediterranean communicate with the main Atlantic Basin over sills which rise nearly to sea-level. In the north the Wyville-Thomson Ridge, from an extension of which the Faroe Islands and Iceland rise, shuts off the deep basins of the Norwegian and Arctic Seas, the latter of which extends across the pole.

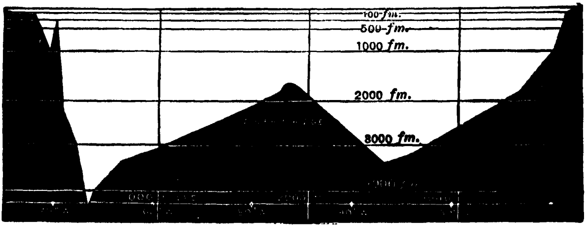

FIG. 38.—Section across Atlantic Ocean in 20° N. lat. The vertical scale is about 300 times greater than the horizontal; the slopes are thus shown 300 times as steep as they really are.

The Pacific Basin.—The Pacific Basin is far more vast than that of the Atlantic, and is much less fully explored; but the operations of surveying ships between the groups of Pacific Islands and of occasional scientific expeditions are gradually revealing new and important facts regarding it. The Pacific Basin appears to form one grand hollow extending from 60° N. to 60° S., between the western edge of the Western World Ridge, and the eastern edge of the Eastern. From 50° N. to 50° S., and right up to the steep walls to east and west, the depth is greater than 2,000 fathoms, and close under the edge of the Western World Ridge, off the west coast of South America, small depressions more than 4,000 fathoms below sea-level have been discovered. The map (Plate XI.)

shows the nature of the slopes of the Pacific Basin to east and west, and brings out the fact that the Pacific and Indian Oceans are connected by shallow water across the top of a steep ridge pitted with small sea-basins of great depth. The floor of the basin slopes up in the south to form the Antarctic Elevation. Numerous groups of long narrow ridges and isolated peaks, rising close to or above the surface of the water, with depressions of various forms between them, stretch roughly parallel to each other from south-east to north-west across the basin, becoming more numerous toward the west. The Pacific Ocean contains the deepest trenches of the ocean floor. The Tonga and Kermadec Trenches run for 1,600 miles, and their deepest points are more than 5,000 fathoms below the surface.

The Japan Trench.—In the extreme north-west the steepest part of the bounding wall of the Pacific Basin rises abruptly, barring off the seas of Japan and Okhotsk, and bearing the chain of Japanese and Kurile Islands. In front of it lies the greatest abyss in the Earth's crust, the Japan Trench. It extends from 23° N. to 50° N. in a crescent-shaped curve, deepening toward the steep slope of the World Ridge to the north-west, where a mighty gully, the Tuscarora Deep, 1,000 miles long and 20 wide lies at a depth greater than 4,000 fathoms (see Fig. 39). This deep, like most of the oceanic trenches, is a great centre for earthquake shocks. South-east of the Japan Trench the floor of the ocean is exceedingly irregular, being broken by parallel ridges separating

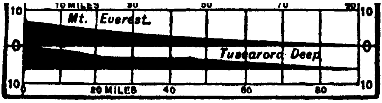

FIG. 39.—Steep slopes. The diagram is divided into squares representing 10 miles in the side. The upper black figure shows the true average slope from the summit of Mount Everest to sea-level; the lower shows the true average slope from sea-level to the bottom of the Tuscarora Deep.

extremely deep trenches, in one of which, the Marianne Trench, lying near the islands of that name, the U.S. surveying ship *Nero* obtained a sounding of 5,269 fathoms, or 31,614 feet, which is the greatest depth that has yet been found.

The Indian Basin.—The Indian Basin, protected on three sides by the inner edges of the great Eastern World Ridge, into which it penetrates, is only half the size of the Atlantic, and one-third of the Pacific, to which it bears some resemblance. The greatest depth is found in the eastern angle between the coasts of north-west Australia and Java, where a depth of 3,800 fathoms was found by the German surveying ship *Planet*, in the Sunda Trench, south of Java. The basin grows gradually shallower toward the south, most gradually toward the south-east. The western half is greatly diversified by narrow ridges running north-eastward from Madagascar to Ceylon, and rising in numerous groups of low islands above the surface of the water.

Islands and Shoals.—Those islands which are merely parts of the crests of the World Ridges separated by shallow water from the mainland, and composed of similar rocks, are termed *Continental Islands. Oceanic Islands* are those which rise from the depressed half of the Earth, and have no geological relation to the neighbouring land. Many of them are composed of volcanic rocks, and must be viewed simply as the summits of ridges or submerged mountains. Others are built up of the remains of living creatures, and rise only a few feet above the surface of the water. These require a foundation before they can be formed, and the foundation is usually a dome or ridge or bank. Submarine elevations of this kind are common in all the oceans, often rising very steeply from a great depth, and having a very small area. When coming so near the surface as to form a danger to navigation they are termed shoals; if deeper, they are called banks or domes.

The Transitional Area.—From mean sphere level the upward slope of the World Ridges is at first gentle, but after a certain height in almost all places it becomes comparatively steep, in rare cases even forming a succession of rocky precipices. Fig. 39 shows that the average slope from the summit of Mount Everest to sea-level is very little steeper than the slope from sea-level to the bottom of the Tuscarora Deep—about 1 in 15, or nearly 4°. The steepness of sloping land almost always appears greater to the eye than it actually is. Only precipices of bare rock have an angle of slope greater than 45° or a gradient of 1 in 1, and the steep slope of the lower part of the World Ridges is known in some cases, though rarely, to reach 40°. The steepest hill on a well-made road is 1 in 20, or an angle of 3°, and the sides of many submarine trenches are twice as steep as this on the average. Mr. J. Y. Buchanan found that in some cases where the slope was comparatively slight, the original rocky wall had been covered by a mound of sediment brought down from the neighbouring land by great rivers. In nearly all cases at the top of the acclivity, usually at the point where the depth of water is about 100 fathoms, the slope suddenly becomes much more gentle, and continues very gradual up to the coast-line. This gentle slope has been termed the *Continental Shelf.* The typical profile of the transitional area is given in Fig. 40, which represents the slope of part of the Gulf of Guinea. The outer curve shows the slope at a part of the coast where a pile of river-mud has been thrown down like an embankment in front of the ridge face, thereby reducing its gradient. These slopes are represented forty times steeper

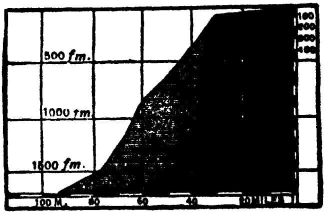

FIG. 40.—Slopes of the Gulf of Guinea. The vertical scale is 40 times the horizontal. Solid black shows average slope of the coast edge; the shaded part shows slope modified by river-borne deposits.

than they are in order to bring out the change of gradient, the vertical scale being forty times the horizontal.

The Continental Shelf.—The World Ridges forming the walls of the ocean-basins are flattened at the top like the rim of a soup plate, and beyond the flat edge the continent itself rises. The breadth of the Continental Shelf varies greatly. In the map (Plate XI.) the area of the shelf is left white, and it will be seen to attain its maximum breadth off western Europe where the British Islands stand upon it, off south-eastern America where it bears the Falkland Islands, around Florida, at intervals along the east coast of Asia, and off the north of Australia. Along the east and west coasts of Africa, and along the west coast of America, it is very narrow, and around some volcanic islands it is entirely absent. The depth of the outer edge of the Continental Shelf when the abrupt change of slope takes place is, in rare cases, as much as 200 or even 300 fathoms, but usually it is very near the line of soundings of 100 fathoms, or not far from that of 200 metres. The total area of the Continental Shelf, covered with water less than 100 fathoms deep, is about 10,000,000 square miles. This includes the whole of many shallow seas, such as the North Sea, the Baltic, the White Sea, Hudson's Bay, and the Yellow Sea, and unites all the great continental islands, except Madagascar, Celebes, and New Zealand, to their nearest continent. The land bordering the coast-line is in most places a low undulating plain, which rises gradually inland until it attains an elevation of about 600 feet above the sea, and then rises more abruptly to much greater heights. The low plains (under 600 feet in elevation) measure altogether about 12,000,000 square miles. From the margin of the Continental Shelf to the end of the low plains there is therefore an expanse of 22,000,000 square miles, the level of which differs by only 1,200 feet. Except possibly on the floor of the Abysmal Area, there is no other part of the Earth's surface where so wide an expanse possesses such a slight range of elevation; and it is significant that the coast-line at present almost bisects it, occupying the only position in which a rise of 600 feet in the sea would submerge, and a fall of 600 feet would lay bare, so large an area.

Beach Formation.—The upper margin of the Transitional Area is a region of great activity and rapid change. Tide and wind together urge the water against the land and withdraw it, dragging back the solid material it has seized. If the land is a low plain of very gentle slope the waves gradually encroach upon it, drawing the sand or soil seaward at every tide and building up the Continental Shelf nearly to sea-level for a considerable distance, as, for example, along the east coast of India. Sandbanks, or bars, sometimes locking in lagoons of salt water and forming a lace-like margin to the land, are produced where river deposits are brought down to the coast—for instance, on the south-east coast of North America, and in the vast mangrove-grown mudbanks of many parts of South America and Africa. Where the land is high and rocky the broken-off stones are rolled and rounded by the waves and used as battering-rams to break away the land; finally, the fragments are swept out to sea and spread out in sheets over the bottom, the level of which is raised and the slope reduced. In this way a beach is formed, the upper part of it being quarried out of the solid land, and forming a notch or ledge (ABC, Fig. 41) on which the sea is always encroaching, while the lower part forms an embankment (CDE) built up of the excavated material which is laid down in beds one above another. The name

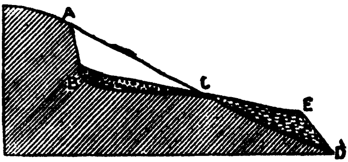

FIG. 41.—Formation of a Beach. AD, original slope of land; ABC, notch cut out by wave action; CDE, embankment of sand, etc. (worn-down rock); BC, gravel resting on beach.

Beach is restricted to the strip of land covered and laid bare by the tides. On a typical beach large stones are usually found heaped up near high-water mark; smaller pebbles, rounded by the sea, form a steeply sloping bank at a lower elevation, and are rattled to and fro, ground against each other, reduced in size to fine shingle, and raked nearer the sea by every tide. Next, there is a wide stretch of sand, which usually consists of quartz grains, resulting from the breaking down of the pebbles. Nearest the sea, uncovered at the lowest spring ebbs, banks of mud are formed of the finest powdered rocks, which can be carried to the greatest distance. Sometimes steep cliffs occur, at the base of which the rushing tides permit no fragments to accumulate. In other cases the beach may consist exclusively of ridges of shingle which are carried along the coast by waves and tide, or heaped up to form forelands.

Wave Action.—The measurements of Mr. Thomas Stevenson on the coast of Scotland showed that during severe storms the waves may exert a force equal to 3 tons on every square foot of the cliffs they beat against. A force of 1 ton per square foot is commonly exerted by the waves of the Atlantic in winter, and 600 lbs. on the square foot in summer. This ponderous surge of the waves tears off loose pieces of rock, and the deluge of spray and pebbles which the breakers toss into the air has been known to break the windows of a lighthouse 300 feet above the sea. When a wave swells up against a cliff it powerfully compresses the air in all the cracks of the rock, thus striking a sudden blow throughout the whole mass. An explosive expansion of the air follows when the wave subsides, and the loosened fragments are sucked out along the lines of bedding or jointing. This action and the bombardment by pebbles are the chief agents in forming sea-caves. As the cave extends into the cliff it grows narrower, and finally a long diagonal tunnel may be drilled out, opening on to the upland far from the shore. Such openings or *blow-holes* are common along all cliff-girdled coasts, and throw up columns of spray during storms, often with a noise resembling the outburst of a geyser. Blow-holes naturally widen as the sides are weathered, and form deep isolated pools where the tidal water rises and falls at the bottom of a nearly vertical rocky shaft. When softer and harder rocks alternate along a coast, the former are in time cut back by the waves and form bays, while the latter are left projecting as headlands. Currents, or tidal eddies, attacking a narrow headland on both sides, often break a cave right through, which may form a tunnel or a natural bridge. Atmospheric erosion may cut as rapidly above as the waves do below, and a headland may thus become separated from the mainland as an isolated rock or stack, round the base of which the water sweeps. Some of the finest examples of such cliff scenery occur on the north coast of Scotland and in Orkney, where the Old Man of Hoy is a magnificent stack 450 feet in height.

Origin of the Continental Shelf.—The action of waves and tidal currents usually ceases to be perceptible at the depth of 100 fathoms. Beach deposits swept seaward by the waves assist in scooping out and deepening the shore, the final result being, possibly, to eat inward along the top of the wall of the World Ridge until a depth of 100 fathoms is attained. The Continental Shelf is widest on the margins of the oldest continents exposed to the heaviest waves, and may be compared to the line which some chemical solutions etch on the glass bottles containing them. Harder masses resisting the attacks of the waves remain as islands or shoals on the Continental Shelf. Where currents sweeping mud and sand to and fro are checked by some inflection of the coast-line, sand-banks are formed. In many cases it is possible that the Continental Shelf is the end of a low plain submerged by subsidence; in others a low plain may be an upheaved Continental Shelf, and probably wave action is only one of the factors at work. Long furrows of considerable depth cross the Continental Shelf, and there is little doubt that some of these, at least, are old river valleys which have been submerged. In some places these furrows have a peculiar interest, because they detract from the usefulness of the Continental Shelf as a guide to sailors groping their way to land by means of the sounding-line in foggy weather.

Marine Deposits.—Immense quantities of sediment are carried down by rivers into the sea. M. de Lapparent calculates the amount as 33 times greater than all the sand, gravel, and pebbles worn off by tidal and solar energy acting through waves and currents on the coasts. Countless myriads of plants and animals living in the water affect the substances in solution, secreting shells or skeletons which at their death fall to the bottom, and form various kinds of deposits. Sea-water acts chemically on substances exposed to it, producing a further series of changes. In all parts of the ocean not precipitous nor swept by strong currents, the original rock is covered with a mantle of deposits of various thickness, to which the gently-rounded contour of the ocean beds is largely due. Sir John Murray and Professor Renard, in their report on the deposits collected during the *Challenger* Expedition, adopted the following classification, which remains in general use:

MARINE DEPOSITS

1. Deep-Sea Deposits (*beyond* 100 *fathoms*)	Red Clay Radiolarian Ooze Diatom Ooze Globigerina Ooze Pteropod Ooze	I. PELAGIC DEPOSITS, *formed in deep water remote from land.*
	Blue Mud Red Mud Green Mud Volcanic Mud Coral Mud	II. TERRIGENOUS DEPOSITS, *formed in deep and shallow water close to land masses.*
2. Shallow-Water Deposits (*in less than* 100 *fathoms*)—sands, gravels, muds, etc.		
3. Littoral Deposits (*between high and low water marks*)—sands, gravels, muds, etc.		

Terrigenous Deposits.—Sediment, such as fine clayey mud, requires a very long time to settle to the bottom of fresh, and still more of running, water, but in sea-water, especially when the temperature is high, it settles out much more rapidly. The smaller a particle of mud and the deeper the sea, the farther from land may the particle be carried by currents before it falls to the bottom. As a rule, however, land-derived material all reaches the bed of the ocean within 100 or 200 miles of the shore; only in exceptional circumstances does it extend to a greater distance than 300 miles. The line of 250 miles from the coast shown on Plate XII. is practically the boundary of terrigenous deposits. Very large and swift muddy rivers, like the Congo and Amazon, form such exceptions. Congo mud has been found 600 miles from shore. The Arabian Sea and Bay of Bengal are carpeted for nearly 1,000 miles from land by the mud of the Indus and Ganges river systems. Other exceptions result from icebergs, which drop land-derived stones and mud all along the path of the ocean currents which drift them into warm seas. Wind also blows sand or dust far out to sea. Volcanic eruptions throw up quantities of fine dust, which are carried far and wide by the winds and scattered over the whole sea surface. Pumice-stone, being porous, floats for months and probably years, and may be drifted to any part of the ocean before it becomes waterlogged and sinks. All terrigenous deposits, although soft and sticky when wet, fall into a loose powder on being dried, hence the term *Mud* is specially applied to them. Such deposits are characteristic of enclosed seas and of the upper margin of the Transitional Area, which they clothe much as snow clothes a tropical mountain, most thickly on the upper part of the slope. It is estimated that terrigenous deposits cover one-fifth of the area of the oceans, and it is distinctive of these deposits that they are made up of fragments of continental rocks, such as compact limestone, quartz, schist, and gneiss.

Blue Mud.—The littoral deposits, or shore formations, sometimes extend in the form of sand or bars of fine gravel, enclosing hollows filled with mud, right across shallow seas. As a rule, however, deep enclosed seas, margins of islands and of continents for 200 or 300 miles from land, are carpeted with extremely fine mud, containing small grains of sand and the remains of shells and of marine plants. Where the material is derived mainly from rivers it assumes the form of a blue mud, which is the most characteristic of terrigenous deposits in every ocean, and is found at all depths. Blue mud owes its dark blue or slaty colour to chemical changes produced by decomposing vegetation, which is often very abundant in river mud. The sulphates of sea-water are reduced to sulphides in this way, and decompose the ferric oxide abounding in all deposits into sulphide of iron and ferrous oxide. When there is much iron in the state of ferric oxide, as in the ochrey muds that redden the waters of the Amazon, there may not be sufficient organic matter to reduce it all, and the mud retains its red colour. Blue mud contains variable quantities of carbonate of lime according to the abundance of shell-producing creatures living in the water where it is deposited, but it accumulates so rapidly that shells as a rule form a very small proportion of the whole.

Green Mud.—Along cliff-bound coasts in which few rivers open, terrigenous deposits form very slowly, and to a distance only of 100 miles, or less, from land. The finely ground particles of rock are thus exposed for a long time to the action of sea-water, and undergo extensive chemical changes. A greenish mineral called *Glauconite* is thus produced, which fills up the interior of dead calcareous shells, forming casts which remain when the shells themselves are dissolved away.

Volcanic and Coral Muds and Sands.—Oceanic islands of volcanic origin are surrounded by *Volcanic* Muds or Sands, formed by the wearing down of volcanic rock and its subsequent partial decomposition by the chemical action of sea-water, the fragments of shells which are present being often coated with peroxide of manganese derived from the rocks. Islands of Coral origin are in a similar way surrounded by *Coral* Muds or Sands which consist almost entirely of carbonate of lime. The remains of marine plants (chiefly corallines) often make up a large part of this deposit.

Siliceous and Calcareous Organisms.—Certain minute animals and one-celled plants, rarely visible except by means of the microscope, and possessed of the power of secreting silica from solution in sea-water, are found in the surface layers of all oceans, especially where the salinity is slight. They are classed with other floating organisms under the general name of plankton. Of these the minute plants known as *Diatoms*, abound in cold seas and in estuaries, forming delicate cases or shells exquisitely marked. They probably obtain some of their silica by decomposing the clayey mud of rivers. *Radiolarians*, another class of silica-secreting organisms, frequent warmer water and are not found in estuaries; they form a minute framework or skeleton of glassy spicules often arranged in very complex and beautiful groups. The chief pelagic molluscs living on the surface far from land are a few kinds called *Heteropods* and *Pteropods* and they inhabit tropical seas. Their shells are thin papery cases of carbonate of lime, varying in length from half an inch downward. Innumerable forms of plankton abound in the water down to 200 fathoms. They are most numerous in warm regions, and gradually diminish toward the poles. One class of these is called *Foraminifera*, as they construct dense microscopic shells of carbonate of lime pierced with innumerable little holes, through which the soft substance of the animal projects during life. The most common is a kind called *Globigerina*, on account of its globular form, the largest shells of which are about the size of a small pin's head. The death of countless millions of these minute creatures produces a steady though invisible snowfall of dead bodies falling from the surface layers crowded with ever-renewed life, and gradually subsiding through the cold still depths of water. This takes place over every part of the hydrosphere, but within reach of terrigenous deposits the shells are covered over and buried in the rapidly increasing pile, of which they form a small proportion. Deposits of organic remains are more coherent and plastic than mud, and have received the general name of *Ooze.* Living creatures, such as sponges which make skeletons of silica, calcareous sea-urchins, crabs, and deep-sea corals, exist on the bed of the ocean to all depths, although they are incomparably more abundant in the shallow water near shore.

Pteropod Ooze is formed of the shells of all surface-living organisms in tropical seas, and contains a considerable proportion of pteropods, whence its name. It is never found below mean sphere level (p. 208), but abounds on submarine elevations rising to within 1,000 fathoms of the surface. The reason of this distribution appears to be that the delicate shells of pteropods expose a very large surface to the sea-water as they fall through it, and are dissolved away before they reach the bottom when the depth is great.

Globigerina Ooze.—The small dense shells of the Globigerina can fall through a far greater depth than the thin pteropods before they are dissolved. Globigerina ooze accordingly covers a far greater part of the ocean bed. It does not occur in enclosed seas, nor under the cold currents of the north-east Atlantic, nor in the Southern Ocean south of 55° S.; but otherwise it is practically universal within certain limits of depth. Under the Gulf Stream its deposit is carried far to the north, as the surface water of that current swarms with globigerinæ. The ooze is a white or pinkish substance, which when dried is seen to have a fine granular structure, due to the little round shells of which it is composed. It varies in composition with the depth, that which has formed in the deepest water containing only the stronger and denser species, and the shells of these even being much corroded. The percentage of carbonate of lime varies from 30 to over 80, sometimes reaching 95; and if the carbonate is dissolved by a weak acid, the residue consists of a fine clayey substance mixed with the cases of diatoms and the spicules of radiolarians. At depths exceeding 2,500 fathoms, with rare exceptions, none of this ooze occurs, the proportion of carbonate of lime in the deposit being reduced almost to the vanishing point. Globigerina ooze borders the upper zone of the Abysmal Area, and thins away toward the great depths (see Fig. 43).

Radiolarian and Diatom Oozes.—The siliceous skeletons of radiolarians and diatoms are present in small amount in almost every deposit. Silica is not nearly so soluble as carbonate of lime in sea-water; hence when the depth is greater than 2,500 fathoms, and radiolarians abound on the surface, their spicules form a large proportion of the deposits reaching the bottom. The name of **Radiolarian Ooze** is given when they amount to more than 25 per cent. Radiolarian ooze is spread over a considerable part of the central Pacific and the east of the Indian Ocean, where the greatest depths occur, but it is not found in the Atlantic or the Southern Ocean. **Diatom Ooze** contains about 50 per cent. of diatom skeletons, mixed with from 10 to 20 per cent. of carbonate of lime. It is the distinctive deposit of the Southern Ocean, where it occurs at all depths; the small number of foraminifera living in the cold and comparatively fresh surface water accounts for the small quantity of carbonate of lime in the deposits of that region. The whole Southern Ocean is within the limits of icebergs drifting from the Antarctic region, and the Diatom ooze often contains a considerable proportion of terrigenous deposit, the study of which gave the first scientific proof of the existence of a great Antarctic continent.

Red Clay.—The deepest parts of every ocean far from shore are covered with a stiff clay of a deep brown or red colour, containing little or no carbonate of lime. Red clay is the distinctive deposit of the Abysmal Area, toward the upper margin of which it passes very gradually into Globigerina ooze; and where radiolarians abound on the surface, the accumulation of their spicules gives to it the name of Radiolarian ooze. It covers more than half the area of the Pacific Ocean. Red clay is exactly like the residue of Globigerina ooze after the carbonate of lime has been removed. The snowfall of calcareous shells from the surface of the open ocean melts into solution before reaching the abysmal depths, but the horny remnants of those shells, siliceous relics of life, waterlogged pumice-stone, wind-borne dust from deserts and volcanoes, ultimately settle down and accumulate on the bottom. The rate of deposit of Red clay is incomparably slower than that of any of the oozes. Microscopic examination has revealed as one of the constituents of Red clay cosmic dust from meteorites (p. 94), which, falling uniformly over the Earth's surface, is concealed by the rapid changes going on in every other region but the still Abysmal Area. The red colour of the clay is due to the formation of ferric oxide and peroxide of manganese from decomposing volcanic material. These oxides are also deposited upon any hard objects lying on the sea-floor, and form nodules composed of layer above layer and often attaining the size of a large potato, to which their usual shape is similar. Manganese nodules were dredged up in great numbers by the *Challenger*, and in every case the nucleus on which they had formed was found to be a piece of pumice, or the hard teeth or bones of the larger creatures inhabiting the sea. Sharks' teeth are very numerous, and also bits of the hardest bones of whales. Red clay also contains in certain localities small but perfectly formed crystals of the class of minerals known as zeolites, which have evidently resulted from chemical changes in the material of the clay. The Red clay is the most strongly radio-active of all forms of oceanic deposits.

Permanence of Elevated and Depressed Regions.—From the scanty supply of materials out of which Red clay is elaborated, it is evident that if the deposit has attained any great thickness it must have been a very long time in course of formation There is no direct evidence as to the thickness of the Red clay except that the longest sounding tubes in use have been driven into it to a depth of two feet; but the teeth and bones found embedded in its nodules are known in many cases to belong to species of sharks which no longer live in the ocean, and must have been extinct for an immense period of time. Moreover, if the Abysmal and Continental Areas had ever changed places, some rocks would almost certainly be found on the land resembling a consolidated Red clay. None such have ever been discovered unless in volcanic oceanic islands that have recently been upheaved. Accordingly the existence of the Red clay is a strong argument that the elevated and depressed halves of the lithosphere have not changed places during past geological ages.

Corals.—Many oceanic islands and reefs are composed in great part of the stony framework of carbonate of lime which is secreted by animals known generally as coral polyps. These polyps belong to the same class as the sea-anemone, and are of many different species, each characterised by some peculiarity in the form of its calcareous support. Some secrete a wide disc, the surface of which is starred with their groups of waving tentacles; others form little cups on which they grow, these cups being either separate, as in the deep-sea corals, or united by a solid stony stem forming many branches. The branching corals of various species are of most importance in reef-building; but they are supplemented in this work by the corallines, various kinds of seaweeds which also form a framework of carbonate of lime. The distribution of coral islands over the oceans depends on the suitability of the water for the life of the polyps and the existence of good foundations. The polyps flourish best in very salt, clear, and warm water; and, although they may live, they do not form reefs where the temperature is less than 70°, or has a yearly range greater than 12°, or a depth greater than 20 fathoms. They are particularly active on the margin of the Red Sea, where the conditions of salinity, temperature, and depth are most favourable. The distribution of reef-building corals is given in the map of Plate XV. Corals are never found near the mouths of great rivers on account of the water being fresh and muddy. They do not build on the west coasts of the tropical continents because of the cold upwelling water. The part of the Somali coast in the Indian Ocean against which the south-west monsoon raises cold water (p. 203) is free from corals on account of the great annual range of temperature which results. Corals are confined to the centre and western sides of tropical oceans, except in warm currents such as the Gulf Stream, which enables them to live luxuriantly far into the temperate zone, the Bermuda Islands, in 32½° N., being in the highest latitude where coral islands are now forming. There the polyps appear able to form reefs at a temperature as low as 68°, but in those reefs the proportion of calcareous seaweeds and worm-tubes is larger than in the Tropics.

Coral Reefs and Islands.—The Gulf of Mexico and the west coast of Florida, the western Indian Ocean, and in particular the western Pacific, are the seats of very active and typical coral growth. There are three distinctive forms of coral structure: (*a*) The *fringing reef*, which closely surrounds the shore, forming on the seaward slope of the land in shallow water, and as it grows older gradually widening toward the sea. (*b*) The *barrier reef*, which usually lies at a distance from the land, running parallel to the coast, and on its seaward side often springing abruptly from great depths. On the landward side a shallow lagoon of still water is shut in by the reef, which is usually broken by several narrow channels, allowing boats or even large vessels to enter. Innumerable volcanic islands in the Pacific, such as the Solomon Islands, the Fiji group, and Tahiti, are encircled with fringing and barrier reefs. The Great Barrier Reef of Australia, stretching for 1,200 miles along the east coast of Queensland, is the finest example known. (*c*) The *atoll*, which is a reef in the form of a closed curve with no land in the centre. The lagoon encircled by an atoll is usually shallow, and the bed of it composed of coral which is either dead or not in vigorous life. Typical examples of the true coral islands or atolls are found in the Maldives, Laccadives, and Chagos groups in the west of the Indian Ocean. These reefs are usually very narrow compared with their length, and their surface never rises higher than from 10 to 20 feet above the sea. In most instances only a portion of the reef rises above the surface, giving the appearance of a chain of low islands separated by very shallow water. The coral polyp dies when it reaches sea-level, but blocks of coral are broken off by the waves and thrown on the reef, where they get broken down into sand, and this becoming compacted amongst the branches of living coral, is raised by degrees until it forms dry land. Water percolating through the coral rock and sand gradually converts the whole into a solid mass of coral limestone, part of the carbonate of lime being dissolved and re-deposited in a crystalline form in the crevices. Drifting pumice strands on the beach and weathers into clay for the formation of soil. Ultimately, the seeds of trees and other plants get drifted to the islands and take root, birds visit them, and the coral island becomes habitable.

The Formation of Coral Islands.—During the famous voyage of H.M.S. *Beagle*, Charles Darwin made a detailed examination of several coral formations, and he came to the conclusion that the three typical forms were closely related to each other. He recognised that, as suggested by von Chamisso, who accompanied Kotzebue on an earlier circumnavigation, it was possible for atolls to form if they had a submarine bank, the top of which was less than 20 fathoms below the surface, as a foundation, but he did not know that such banks often occurred. He found also that the walls of coral rock on the seaward face of reefs sometimes rose from an enormous depth, and since coral polyps can only live and build in the warm surface layer, he concluded that the corals had built in that layer, but that the foundations had been gradually sinking. Thus he supposed a fringing reef (I, Fig. 42) to form round a volcanic island, and as the island slowly subsided the corals built the reef higher and higher, keeping pace with the subsidence. In time, as the outer edge of the coral grows fastest on account of the greater abundance of oxygen in the breakers, the reef would widen and grow higher seaward, forming a barrier reef by the time subsidence has brought the sea-level to the position (II). Finally, subsidence submerges the whole mountain below the surface, and the barrier reef continues growing up to form an atoll (III). It has been pointed

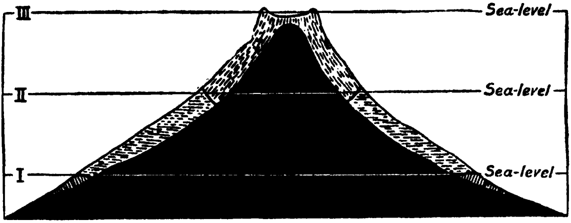

FIG. 42.—Darwin's Theory of the origin of Coral Islands. I, II, and III show successive levels of the sea brought about by subsidence of a volcanic island (solid black). The corresponding coral formations, respectively fringing reef, barrier reef, and atoll, are shown by different shading. (Slopes much exaggerated.)

out by several investigators that atolls are as common in areas which are being gradually elevated as in those that are subsiding. Dr. Guppy, in the course of a study of the Solomon Islands, where many reefs have been elevated far above sea-level, also found that the coral limestone is never of greater thickness than about 120 feet, and he thus cast doubt on the existence of vast submerged walls of coral. He found that the cake of coral rock rested either on volcanic rock or on rocks formed by the consolidation of Pteropod or Globigerina ooze.

Murray's Coral Island Theory. — During the cruise of the *Challenger* Sir John Murray formed a theory which has been strikingly confirmed by later observations. He believed, like von Chamisso, that the foundation for coral reefs is in every case supplied by a submarine bank. Some of these may have been formed by volcanic upheaval and then reduced below sea-level by the eroding action of waves, and some may have existed originally at a suitable depth. Others may have been raised to the coral zone by ages of submarine sedimentation, being covered first by Globigerina ooze, then as the depth was gradually diminished by Pteropod ooze, and finally by the accumulation of the remains of sea-urchins, starfish, deep-sea corals, and the like brought comparatively rapidly within reach of reef-builders—first of the plant corallines, then of the animal corals. The reef-

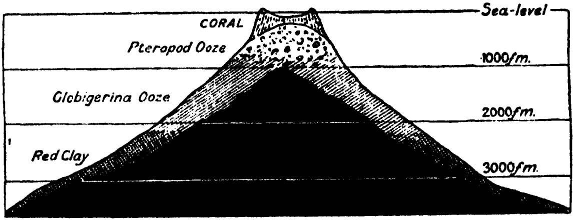

FIG. 43.—Murray's Theory of the origin of Coral Islands. The central volcanic rock (solid black) is shown covered by deep-sea deposits, which build it up to the reef-building zone where an atoll is formed. (Slopes much exaggerated.)

building polyps raise a flat table of solid rock, which, as it approaches the surface, grows more rapidly on the circumference on account of the abundance of food supplied by ocean currents. The rim finally reaches the surface and cuts off the supply of food from the polyps in the interior, which die, and the dead coral is partly dissolved by the water, partly scoured out by tide and waves, and so a lagoon is gradually hollowed. The outer slope of the reef is alive, and ever growing outward. As it becomes steep and wall-like, masses broken off by the waves roll down to the bottom and form a more gentle slope or talus, on which the active corals continue to build seaward, always increasing the diameter of the atoll. Meanwhile, the sea-water in the lagoon is at work dissolving and removing coral from the inner edge, and the island does not increase in width although its circle is continually widening. An atoll is thus supposed to grow like a "fairy-ring" in the grass. Fringing reefs growing seaward in the same way ultimately form barrier reefs, in which the same process of active growth seaward, and decay on the landward side, has been observed. In some cases barrier reefs have grown up directly, far from the island, on the edge of a wide and shallow Continental Shelf, which is formed when a loose volcanic upheaval, such as Graham Island, which appeared in the Pacific, has been worn away by the waves. In 1897 Sir T. W. E. David, of Sydney, made a series of deep borings in the atoll and the lagoon of Funafuti in the Ellice group in the Pacific Ocean, and showed that the mass of pure limestone of organic origin was at least 1,114 feet (186 fathoms) thick. This has been taken as showing that Darwin's theory of the formation of atolls in a region of subsidence is well founded; and it seems reasonable to believe that atolls are, in fact, formed both in that way and also in accordance with Murray's view, which has been powerfully supported by the observations of Professor Alexander Agassiz. More recently Mr. Wayland Vaughan has shown that large quantities of calcium carbonate are precipitated in a crystalline form in shallow tropical seas, and that the foundations on which corals build are in some measure produced in that way.

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CHAPTER XIII

THE CRUST OF THE EARTH

Lithospheric Changes.—In the Abysmal Area the hydrosphere protects the solid rock beneath by allowing of the extremely slow formation of a covering of red clay or ooze. In the Transitional Area, where the hydrosphere is stirred more forcibly by solar energy, the formation of deposits is accompanied by the wearing away of rocks. All our knowledge of the substance and structure of the lithosphere is obtained by studying the processes of change going on in the Continental Area, which alone is open to our inspection. It is subject to much greater changes than the other areas on account of the strong action of solar energy, which through various agents is always crumbling down the heights and carrying the resulting detritus to the sea-margin. In the course of time this action, termed erosion, would, if not counterbalanced, reduce the whole Continental Area below sea-level.

Elevation and Subsidence.—The attention of tourists along the steep coasts of Norway and Scotland is often attracted by lines of horizontal terraces, running parallel to each other at various heights above the shore. These, when examined, are found to be shelves or notches cut out of hard rock or soft ground, frequently covered with pebbles and sand, often containing sea-shells. Behind the terrace the cliffs are sometimes perforated by caves, which show every mark of having been excavated by wave action. The terraces are, in fact, raised beaches, and their position proves that the surface of the sea must have sunk, or the land must have risen, since the waves eroded them. In the south of Scandinavia and the south of England there are many places where the sea now flows over what was dry land even during historical time. This encroachment cannot be due to erosion, as in some cases trunks of trees and walls of buildings may be seen still standing under the shallow water, and the necessary conclusion is that either the level of the sea has risen or the land has sunk. It is difficult to believe that for thousands of years the sea-level has been slowly sinking around Scotland and Norway, and at the same time slowly rising round England and Sweden; and the only satisfactory explanation of the facts is that the land must be undergoing gradual elevation in the north, and gradual subsidence in some parts of the south of Britain and Scandinavia. The regions of recent elevation and subsidence are marked on Plate XV. Since the average height of the land is much above sea-level, it is obvious that upheaval has been more rapid on the whole than erosion, and more general than subsidence in its action over the Continental Area. The study of the composition and changes of the Earth's crust is the special object of geology.

Rocks.—The *word* rock is usually restricted to the hard stony masses of cliffs and mountains, but the *term* rock has a wider meaning. Geologists class as rocks all substances which occur on or in the crust of the Earth and have not been formed by the very recent decay of living creatures. Thus the term rock includes soil, sand, stones, etc., but not bones nor dead leaves. Some rocks are uniform in structure, like white marble or flint, but in most cases rocks appear to be built up of small separate portions which may be broken or rounded grains as in sandstone, large crystals of different compounds as in granite, or minute crystals so tightly packed as to be indistinguishable by the unaided eye, as in basalt. The grains of sandstone or clay are merely fragments of older rocks that have been broken and worn down before becoming cemented together again; but the regularly formed crystals are portions of pure substances, sometimes elements, although usually compounds, and they are known as *minerals.* While the term mineral is restricted to the pure constituents of rocks, the word mineral is often used to include everything useful found in the Earth's crust.

Rock-forming Minerals.—The crystalline minerals which make up many rocks must have formed slowly by the combination of their elements or the decomposition of other compounds. Some were evidently deposited from solution in water, as, for example, rocksalt and gypsum (calcium sulphate); in both these and in some other unimportant instances rocks may be composed of only one mineral. Other rocks have evidently crystallised from a state of fusion; in basalt, for example, the small crowded and imperfect crystals bear evidence of rapid cooling and solidification. Rocks like obsidian, which show a vitreous or glassy texture, quite smooth, and, it may be, free from any appearance of crystals, have evidently been cooled still more quickly, so that crystallisation could not take place. After a rock has been formed its minerals may undergo chemical changes. The process of weathering, or slow alteration of rocks in air, affects some minerals more than others. Many new kinds of mineral result from chemical change brought about by the absorption of oxygen (oxidation), by the absorption of water (hydration) producing zeolites, etc., or by the formation and removal of some product (decomposition). Mineralogists recognise about 800 different minerals, most of which, however, occur in very small quantities. Sixty or seventy only can be considered important as rock formers. Indeed, the bulk of the rocky crust may be said to be composed of felspar, quartz, mica, amphibole, pyroxene, iron oxides, and the products of their alteration.

Igneous Rocks, as a class, include all that have solidified from a state of fusion or have been formed by the accumulation of fragments thrown out by volcanoes. Most of them are dense and hard; they have a glassy or crystalline texture, and the minerals of which they are composed are almost invariably silicates or silica. Silica, as flint, agate, and chalcedony, is also deposited from solution in water, but in that case its form is not crystalline. The way in which igneous rocks occur, whether poured out as lava on the surface or forced as intrusive sheets through beds of other rocks, greatly influences the part they take in determining the scenery of a country.

Sedimentary Rocks result from the consolidation of sediment deposited in lakes or on the margin of the sea. They are recognised by their structure, being built up of shells or of worn rock fragments. Fine muds consolidate into shales, sand into sandstone, gravel or pebbles into fine or coarse conglomerates, sometimes cemented together by the deposition of silica or carbonate of lime. In consequence of their formation in lakes or on the seashore, sedimentary rocks show marks of bedding, the layers or strata having been laid down horizontally or nearly so. The beds of rock are not of uniform thickness throughout, but thin away as the original sediment formed a thinner layer of deposit far from the land. This class also includes rocks formed by the accumulation of remains of animal or plant life, such as decayed vegetation forming coal, and the shells of mollusca or of foraminifera, the skeletons of corals and other lime-secreting creatures giving rise to chalk and limestone.

Metamorphic Rocks.—Changes are produced by heat, pressure, and Earth movements, so that it is difficult in some cases to decide the origin of rocks. It is convenient to class all such doubtful cases as metamorphic or changed, and the changes are of several different kinds. Limestone subjected to heat under pressure crystallises and forms marble; a bed of clay under similar influences is altered into slate. The temperature of rocks deeply buried under a mass of newer sediment is greatly raised, and, as the pressure exerted by the upper layers is extreme, changes of chemical composition and of structure are often produced. When great crust movements fold over and thrust forward masses of rock, the friction produces heat enough to soften the substance which is rolled out, so that the original structure disappears, the minerals are altered chemically, and the rock acquires a flaky texture and is known as *schist.* The change may produce a crystalline structure very similar to that of granite, as in the rock called *gneiss.* Local or contact metamorphism is brought about by an intrusive sheet of liquid igneous rock forcing its way between other strata, and altering their composition and physical state. The edges of sandstone may thus be fused into glassy quartzite, and soft clay beds baked into a hard porcelain-like mass.

Dip, Cleavage, Joints, and Faults.—Sedimentary rocks are sometimes raised by upheaval so steadily and uniformly that the strata remain horizontal, but far more commonly the strata are inclined in a particular direction. The inclination of a bed of rock to the horizon is called its dip, and is measured by the angle FAB (Fig. 44). Rocks are found dipping at

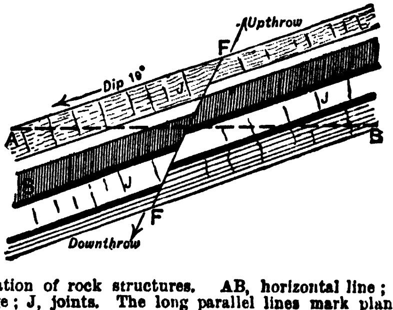


FIG. 44.—Illustration of rock structures. AB, horizontal line; FF, fault; S, slaty cleavage; J, joints. The long parallel lines mark planes of bedding making an angle of 19° with the horizontal.

all angles, sometimes as high as 90°; then the strata stand upright. The stresses which elevate rocks usually act horizontally as a thrust from two sides, and the particles of the rock sometimes yield and are flattened out. When this happens the rocks split up more readily along the flattened sides of the particles than along its original planes of bedding, and are said to have acquired cleavage-planes (straight lines S, in Fig. 44). The cleavage-planes of slate, by means of which thin slabs can be split off, are sometimes at right angles to the planes of bedding. In more rigid rocks the strain during upheaval is relieved by the strata cracking more or less nearly at right angles to the planes of bedding. When these cracks—which are originally extremely narrow, sometimes invisible—simply traverse the rock without any distortion (fine lines JJ), they are termed joint-planes, and it is on account of the existence of joint-planes in all rocks that the quarrying of stones is possible without continual blasting. Igneous rocks show joints, probably the result of contraction in cooling after solidifying. The fine hexagonal columns of basalt cliffs are outlined by joint-planes produced by the uniform cooling of a great mass of rock, the interior of which is brought into a state of great tension by contraction until relieved by cracking into columns. A layer of wheat starch on drying is strained in exactly the same way by contraction throughout the mass, and similarly cracks into many-sided columns. The same phenomenon may be observed in beds of clay when they contract in dry weather. When the rocks on one side slip along a crack so that the strata no longer correspond (F, Fig. 44), the crack is termed a fault; the lower side is called the downthrow, the upper the upthrow. Parallel lines of faults usually mark the borders of regions where upheaval has taken place and the strata preserve a low dip. When a strip of land sinks between parallel lines of faults it forms a *rift valley* like that of the Dead Sea; when, on the other hand, a block of land outlined by faults is thrust up, or the surrounding land dropped down, it forms a steep flat-topped mountain termed a *horst;* but most frequently when a fault occurs there is no surface feature to show it, as simultaneous erosion prevents the formation of any inequality.

Temperature of the Earth's Crust.—Whatever be the nature of the surface rocks, the Sun's heat penetrates them slightly and slowly. By observations in Britain with thermometers fixed at various depths beneath the surface, it has been proved that the difference of day and night temperatures vanishes at about 3 feet, and that the greater and more regular difference between summer heat and winter cold becomes less and less perceptible as the distance increases, and dies away within 40 feet. The average temperature shown by the rock thermometers on the Calton Hill, at Edinburgh, during the eight years 1880-1887 were, at the depth of 2 feet, 39°·4 in February and 53°·0 in July, an annual range of 13°·6, with the minimum and maximum in winter and summer respectively; and at the depth of 20 feet, 46°·9 in January and 45°·4 in July, a range of only 1°·5, with the maximum temperature in winter and the minimum in summer, showing that it requires six months for the conduction of heat from the surface to the depth of 20 feet. A zone of invariable temperature lies beyond the reach of solar heat, and is found at different depths in different places, being deeper in regions of great annual range of temperature, and only a few feet from the surface in the Tropics. Beneath the invariable zone, temperature increases with depth in all parts of the world. In deep mines the air is always oppressively hot, and the water from deep artesian wells is warm in proportion to their depth. The Underground Temperature Committee of the British Association, after collecting many observations of temperature at great depths, concluded that the rate at which temperature increases downward averages 1° in each 55 feet. In some instances the increase is more rapid, in others less so, according to the conducting power of the rocks. The temperature 1 mile beneath the surface must be about 100° higher than that of the invariable layer, and at the depth of 30 miles the temperature must be high enough to melt all known substances. Professor Tait calculated, from the gradient of temperature and the conductivity of rocks, that through every square foot of surface the interior of the Earth is losing heat at the rate of 230 units per annum, or sufficient to warm 1¼ lbs. of water from the freezing to the boiling point.

Interior of the Lithosphere.—Surface rocks have an average density of 2·5, and the deep-seated igneous rocks a density of about 3·0, while the mean density of the Earth, as a whole, is 5·5. Unless the enormous internal pressure of the weight of the Earth's mass were counteracted, the rock substance would be compressed into less space, and the mean density of the Earth would be greatly raised. The high temperature of the interior causes the rock substance to expand against the pressure of gravity, and so maintains the comparatively low mean density which is actually found. The great pressure, in its turn, may possibly act by raising the melting-point of the rock substance, and so preventing it from assuming the liquid state. Astronomical observations show that the Earth behaves as if it were a solid ball, and Lord Kelvin calculated that it must be as rigid as steel. Professor Arrhenius suggests that the temperature in the interior of the Earth is so high that the greater part of the globe is in a gaseous state far above its critical temperature, but so highly compressed as to act on the whole like a solid. He pictures the innermost core as a sphere of gaseous iron 6,400 miles in diameter, surrounded by a layer of gaseous rock about 600 miles thick, which is followed by a layer of liquid rock about 150 miles thick, and the whole enclosed in a solid crust about 40 miles in thickness.

Volcanic Action. — Volcanoes are openings in the Earth's crust which continually or occasionally throw out steam, hot stones, or white-hot melted rock called lava. These openings are often situated on the summits of conical mountains. There are many theories as to the causes of volcanic action. It is supposed by some authorities that the crust of the Earth is honeycombed by reservoirs containing liquid rock which escapes through any crack to the surface. The origin of the heat which maintains the rock in a state of fusion is ascribed by some to the conversion of motion in the shrinking crust into heat, and by others to radio-activity in the deep-seated rocks. Other authorities point out that since the bulk of the globe, if solid, is solid only on account of the pressure of the crust upon it, any relief of pressure produced by shrinking in the central mass, or by cracking of the crust, must allow the rock substance to liquefy suddenly and with explosive violence. All volcanic activity is accompanied by the emission of great quantities of steam, to the expansion of which geologists believe the great power of volcanic explosions is due. It is probable that a good deal of underground water finds its way down into the heated layers under the crust, there combining chemically with the rock under pressure, but always ready to resume the form of steam if the pressure is relaxed.

Volcanic Materials.—In addition to water-vapour, volcanoes throw out other *gases* in great abundance. Hydrogen and oxygen, resulting from the dissociation of water at high temperature, combine as they rush out, producing violent explosions and great flames. These flames, together with the reflection of glowing liquid rock on the overhanging vapour, gave to volcanoes the popular name of burning mountains. Sulphurous acid, sulphuretted hydrogen, nitrogen, carbonic acid, hydrochloric acid, and the vapour of boric acid, are also emitted frequently. An eruption of gases mixed with incandescent dust, and descending like a dense cloud of fire occurred at Mont Pelée, in Martinique, in 1902, and destroyed the town of St.

Pierre. *Lava*, or molten rock, is the most important of all volcanic products. Welling over the cup-like hollow at the summit, it flows down the sides of the mountain in white-hot streams, which gradually solidify on the outside, and advance like a glacier of slow-moving viscous rock, ultimately hardening into crystalline igneous rocks, such as basalt and trachyte. *Pumice* is a sponge-like glassy rock which forms over the surface of certain lavas, being frothed up by the vapours which are continuously given off. *Scoriæ* are the rough cindery upper portions of very viscous lavas formed in the same way. During eruption immense quantities of these crusts of lava are thrown out. The finer grained loose materials are known as *dust* or *volcanic sand*. A light gray powder, known from its appearance as *ash*, is the solidified spray of molten rock similarly thrown into the air by the explosion of escaping vapours.

Volcanic Mountains.—Wherever a crack or fissure of the Earth's crust allows volcanic activity to assert itself, the material driven out from below accumulates and solidifies on the foundation of the surface rocks, which are usually sedimentary, and a cone or *mountain of accumulation* is thus piled up. If the lava is very fluid and escapes from a long fissure, it may flood extensive tracts of land with nearly level sheets. Such lava floods now occur very rarely, but they were common in past ages. Volcanoes are usually connected with their subterranean lava-stores by a comparatively narrow pipe, in which the lava wells up and overflows. A very hot and fluid lava forms a hill of gentle slope; a cooler or viscous lava, which solidifies before it flows far, builds a steeper mound. In either case the centre is formed by a trumpet-shaped hollow called the crater, the rim of which is raised by each successive outflow. In some instances cones are built up round the orifice of a volcano before the flow of lava commences, and are composed of volcanic ashes, pumice, and broken stones, the ejection of which is the prelude to an eruption. When compacted by the pressure of its own weight, and cemented together by the chemical action of rain, such a deposit forms the rock known as *volcanic tuff*. When fluid lava rises in the pipe of a tuff cone, the pressure it exerts frequently bursts an opening in the side, through which a stream of lava escapes. When the force of the eruption is small and the walls of the cone strong, the ascending lava may cool down in the funnel and seal the volcano by solidifying. The most common form of volcanic mountain is of composite structure, being built up of alternate layers of tuff and flows of lava. Such a cone grows slowly, and, as represented in Fig. 45, is the outcome of several periods of activity and quiescence. The explosions which herald a new eruption shake the mountain, and cracking the walls allow tongues of lava to penetrate in all directions from the central shaft. These sometimes force a way to the exterior and form small cones on its slopes, from which streams of lava flow. Sometimes they harden as *dykes* or walls in the fissures into which they were injected.

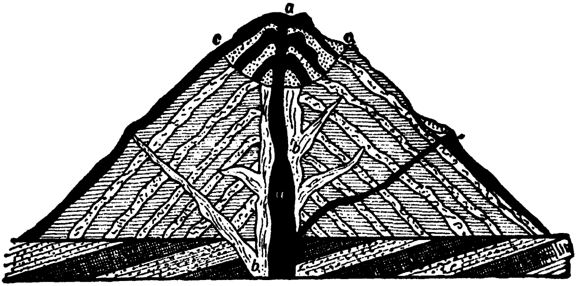


FIG. 45.—Ideal Section of a volcano. *SS*, stratified rocks of crust; *bb*, old lava solidified in throat of volcano and in dykes; *aa*, new outburst of lava; *cc*, old crater; *a*, new crater. (After J. Geikie. Steepness greatly exaggerated.)

Volcanic Eruptions.—Volcanoes are often classed as active, dormant, and extinct. Stromboli, in the Mediterranean, is the type of a continuously and moderately active volcano. It serves as a natural lighthouse and also as an automatic storm warning, as its activity is always greatest when the atmospheric pressure is low and gales may be expected, while the violence of its eruptions is reduced when the barometer rises. Volcanoes from which no eruption has ever been recorded are called extinct; those which break out at intervals are said to be dormant during their periods of tranquillity, but the distinction can hardly be drawn with confidence. Vesuvius is the type of volcanoes which are occasionally dormant and sometimes supposed to be extinct. The volcano Bandaisan was dormant for probably a thousand years at least before its great outbreak in 1888. The commencement of activity after a dormant period is usually preceded by earthquakes and subterranean noises, indicating that pressure is accumulating in the heart of the mountain. Hot springs break out on the slopes, and gases and hot vapour rise in increasing volume from the crevices in the crater. Then a terrific explosion occurs, shattering the solid lava plug and perhaps destroying the entire cone; volumes of water-vapour shoot up into the air, mixed with clouds of dust that darken the sky and fall like snow over the mountain slopes and surrounding country. Flashes of lightning dart from the overhanging cloud, the friction of dust and vapour on the air causing great electrical disturbance, and the noise of thunder is added to the roar of the escaping steam and volcanic explosions. The cloud reflects the fierce glare of the lava welling up in the crater, from which the explosions and bombardment of heated stones become more frequent, until finally the molten rock surges up to the lip and pours over as a river of fire. The vast quantities of water-vapour meanwhile condense into floods of rain, which convert the dust-strewn slopes into torrents of hot mud, more voluminous and often more important in obliterating the surface features of the scenery than the lava itself. Such a mud deluge destroyed the Roman town Herculaneum when the first recorded eruption of Vesuvius took place in the year 79. Snow-clad volcanoes like Etna and Cotopaxi send down still more serious floods on account of the sudden melting of their snow.

Krakatoa.—On 27th August, 1883, the volcano of Krakatoa, a small island in the middle of the Strait of Sunda, terminated a set of comparatively quiet eruptions by the most terrific explosion which has ever been witnessed. A great crater had been previously formed, and sea-water is supposed to have gained access to the crater full of molten lava as the mountain walls were gradually broken down. The result was a temporary reduction of activity as the cold water chilled the surface, and then the grand explosion shot out a column of dust and vapour 20 miles high with a roar that was heard at Rodriguez, 3,000 miles distant, and attracted attention over one-thirteenth of the surface of the globe. The concussion caused by this explosion was severe enough to break windows and crack walls in Batavia, 100 miles away, and the disturbance of the air was shown by the records of barographs to have expanded as an air-wave from Krakatoa until it spread round a great circle 180° in diameter, then contracted to the antipodes of Krakatoa, whence it was reflected back, and so continued pulsing round the world four times from the centre of disturbance to the antipodes, and three times back again. Two-thirds of the island were blown away, most of the material being deposited in the Strait of Sunda, where several new islands formed of piles of tuff and ashes appeared, and after a few months were washed away by the waves. For weeks fields of floating pumice made navigation very difficult. The disturbance in the sea produced a wave more than 100 feet in height, which rushed upon the neighbouring coasts, overwhelming lighthouses and towns, and stranding ocean steamers in inland valleys. More than 36,000 people were washed away and drowned. Part of Krakatoa was scattered as the finest dust through the air and carried to every part of the Earth, its presence being detected in rain, and by the magnificent red sunsets that were visible everywhere during the autumn and winter of 1883 and 1884.

Distribution of Volcanoes.—Volcanoes are usually found in the line of great mountain chains and near the sea coast. They form a "ring of fire" round the Pacific Ocean, being very numerous in the Andes, and more widely spaced along the plateau of Central America, the coast ranges of North America, and the Aleutian Islands. Thence they increase in frequency along the island festoons of Asia, and come to a maximum in the Malay Archipelago and New Zealand, and appear once more in Antarctica. The West Indies, many of the small Atlantic islands, the Mediterranean coasts, Iceland, and Jan Mayen, also contain active volcanoes, and undoubted volcanoes have recently been reported in the centre of Asia and of Africa. The distribution of active volcanoes is shown in Plate II.

Earthquakes.—The crust of the Earth is elastic, and readily transmits wave-motion. Any cause which produces a local disturbance of the crust sets up a series of waves, which may become apparent on the surface in the quick up-and-down or to-and-fro shaking of the land called an earthquake. Earthquakes of considerable severity accompany volcanic action, and are accounted for by the jarring of the Earth's crust by successive explosions, but they are by no means confined to volcanic regions. The falling-in of underground caverns may give rise to earthquakes of slight intensity. Very severe shocks accompany the elevation of land when that process takes place in sudden steps of a few inches or a few feet at a time, in consequence probably of the strata, subjected to the powerful stresses set up by the contracting Earth, snapping under the strain. Every large fault found in rocks must have given rise to earthquakes. Professor Milne points out that most shocks originate along the lower part of the steeper slopes of the World Ridges. This coincides with the lines along which the process of elevation is going on most rapidly, and where the strata are consequently subject to accumulating stresses. The regions in which earthquakes are common are coloured light blue on Plate II. and those where they are very severe and frequent are coloured in a darker shade. Some geologists think that sea-water, filtering through the bed of the ocean or buried to a great depth in the lower layers of terrigenous deposits, causes explosions in the intensely heated region below, and that all great earthquakes originate from this cause and are essentially volcanic; the upheavals accompanying earthquakes would thus be reckoned as their consequences, not their causes.

Propagation of Earthquakes.—If the crust of the Earth were perfectly uniform in substance, and a shock were communicated to it at any point by a sudden yielding to stress, a wave would spread in concentric spherical shells from that centre like the sound-wave from a vibrating bell in air. In the rock the wave travels more rapidly than in air, and the to-and-fro movement of each particle passing it on is very small. If the shock is given at A (Fig. 46) the circles I, II, III show the position of the crest of the wave at intervals of 1, 2, 3 seconds. The wave is shown reaching the surface at B, directly over the centre of disturbance, in 3 seconds; there it strikes perpendicularly from beneath, although the force of the shock is greatest at a little distance from B. A second later the wave reaches the surface along a circular path (IV-IV), and strikes obliquely upward; at the position reached in the next second, the stroke is still more oblique along a wider circle, and is more

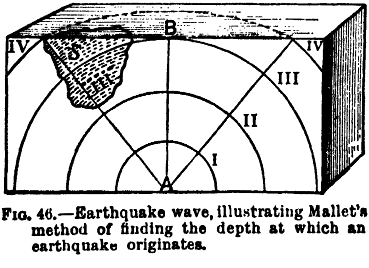


FIG. 46.—Earthquake wave, illustrating Mallet's method of finding the depth at which an earthquake originates.

feeble on account of loss of energy due to friction among the rock particles. The distance of the centre of disturbance beneath the surface may be calculated by observing the angle from which the shock comes at different points, and constructing a diagram somewhat like the above. It appears from many observations recorded by Mallet and others that the depth of origin rarely or never exceeds 35 miles. Although the crust of the Earth is probably homogeneous at a considerable depth, it is very far from being so in its upper part, and the earth-wave consequently travels at an unequal rate in different directions as it nears the surface. A thick bed of sand or loosely compacted and inelastic stones (*S*, in Fig. 46) greatly retards and may entirely absorb the wave by friction between the particles, so that no shock would be felt on the surface, while houses built on the hard rock all round would be shaken severely. On the other hand, a small deposit of sand or alluvial soil occupying a shallow hollow would be jarred by confused earth-waves from every side, and buildings on it damaged most severely.

Earthquake Shocks.—The area of the surface shaken depends on the intensity of the original shock and the nature of the Earth's crust at the place where it occurs. The memorable earthquake that destroyed Lisbon in 1755 shook a space four times as large as Europe, and probably made the whole Earth tremble; and that which damaged Charlestown in 1886 was felt over 3,000,000 square miles, from Cuba to Canada, and from Bermuda to the west of Missouri State. By the use of delicate seismometers the dying tremor of an earthquake-wave may be detected at a great distance, beyond the limit of unaided observation. Thus the tremor of earthquakes in Italy, India, and Japan is distinctly recorded by instruments in Great Britain. The shaking of the Earth's crust throws down any slenderly supported rock masses like perched blocks, natural bridges, and earth pillars, and when such structures are conspicuous features of the scenery, the district may be reckoned free from risk of serious shocks. Landslips, the opening of great fissures, and other surface changes often result from earthquakes, which may thus alter the course of rivers and form or drain lakes. But the occasional destruction of cities and houses, and the peculiar sensation of terror and helplessness which earthquakes produce in most minds, are apt to give an erroneous and much exaggerated idea of the power of such shocks in forming the scenery of the globe. The researches of Professor Milne and other scientific men in Japan, and the extensive use of seismometers, or earthquake measurers, and latterly the investigations of the International Seismological Association, with observers in all the continents, have thrown much light on the nature of shocks and tremors. The to-and-fro or up-and-down motion of the Earth in a shock severe enough to throw down houses is probably not much more than an inch. It is the shaking produced by the complex disturbance rather than the actual lifting of the surface that produces destructive effects. Some of the tremors detected by seismometers are not produced by the internal energy of the Earth. It has been proved in Italy that changes of atmospheric pressure jar the elastic and sensitive crust; and in Japan a gale blowing against a range of mountains has been found to set the greater part of the island quivering; while a distinct tilting of the surface has been detected in the Isle of Wight as the result of a heavy local fall of rain.

Folding of the Earth's Crust.—The Earth necessarily contracts as it cools, and the crust composed of stratified rocks falls into folds in order to adapt itself to the reduced area of the globe, just as the skin of an apple gradually becomes wrinkled in adapting itself to the drying and shrinking fruit. Reasons have been given on p. 227 for believing that from a very early period the Abysmal and Continental Areas have occupied their present position, and possibly they represent the troughs and crests of the earliest Earth folds. The primitive furrows themselves must have disappeared as the crests were worn away by erosion, and the resulting sediment was deposited on the upper slopes of the hollows, to be consolidated in turn and form part of a new set of folds, which shared the same fate and passed on the process. Some geologists believe that as denudation lightens the ridges and loads the hollows, the Earth's crust is strained by the redistribution of the pressure on it: that consequently the strata snap with a succession of earthquake shocks, and the parts loaded with deposits sink, while those lightened by the effect of erosion are upraised. Other geologists take an opposite view of the result of sedimentation. The typical form of an Earth fold is a gentle ridge, A, accompanied by a gentle hollow, *S* (Fig. 47). The curved strata of the ridge are said to form an anticline, because at the summit, A, the strata, as shown by the arrows, dip or incline away from each other. The curved strata of the trough are similarly said to form a syncline, as at *S* the strata dip together or toward each other. Even although the wrinkled crust should be worn smooth by erosion to form the surface *ss'*, it is still possible to tell, by observing the dip of the strata, where the ridge and the hollow were situated. Thus rock structure is not concealed by surface change. Synclines and anticlines are ridged up in consequence of the lateral pressure or tangential thrust produced by the down-

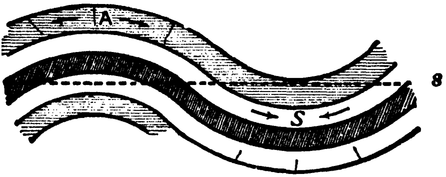


FIG. 47.—Strata bent into anticline A and syncline *S*.

sinking of part of the crust. The tremendous lateral pressure effected by great subsidences throws the strata on both sides into sharp anticlines and synclines, while at a greater distance from the origin the wrinkles are low and uniform. The Geological Survey of Scotland has brought to light many remarkable proofs of the intensity of the thrust which ridged up the western margin of Europe in ancient times. Sometimes the compressing force was so violent that the strata, instead of puckering up into anticlines and synclines, cracked, and allowed one part to be lifted up and thrust bodily over the other, in certain cases for a distance of ten miles or more. The consequent crushing, faulting, and folding produced a very confused arrangement of the rocks, and extensive metamorphism.

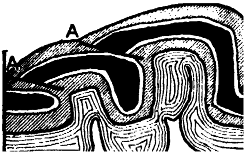


FIG. 48.—Production of thrust-planes A. The strata represented are layers of clay and sand separated by cloth; they were laid down horizontally, and ridged into the position shown by a thrust acting in the direction of the arrow. (From a series of experiments by Mr. H. M. Cadell.)

Mountains of Elevation.—When lateral compression of the Earth's crust takes place, the strata pucker up along the line where they are weakest, and are thrown into a series of anticlines and synclines growing sharper and higher toward the central line. The rocks in the interior of the mass and those occupying the hollows of the synclines are necessarily compressed, heated, and altered, while those on the outer curves of the anticlines are stretched and split in the process. A mountain range is formed in this way, with anticlines as ridges and synclines as longitudinal valleys between them, the slopes of the surface corresponding to the dip of the strata. The true mountain ranges of the world are all of this character, the Alps, Himalayas, and Andes being typical examples, and it is significant that all such ranges are situated near the edge of great depressions, the subsidence of which probably accounts for their uplifting. Rocks of recent sedimentary origin always form the first gentle undulations on the slope of a mountain range, but toward the main ridge the strata are of greater age and more contorted, while in the centre there are masses of schistose or igneous rocks, probably produced either by the rolling and compression of the uplifted strata or by volcanic action from below. Fig. 49 represents a section across the chain of the Alps from north to south, the dotted lines indicating the anticlinal arch. Erosion by solar energy probably accompanies the whole process of ridging up a mountain range, and after the elevation is complete the aspect of its scenery, the form of its slopes and valleys, are increasingly due to this cause. Streams, perhaps guided by cracks, flowing down the slopes of the long mountain ridges, hollow transverse valleys, and so cut the ridge into peaks. Two transverse valleys meeting in a col, or pass, allow of easy access between the longitudinal valleys which lie between the ridges. Anticlines are much more rapidly eroded than horizontal strata, even when the surface may have the same slope, for the direction of the joint planes and the dip of the rocks favour the formation of landslips. An anticlinal mountain may be viewed as geologically unstable, like a pile of inverted saucers. In many cases the low mountains of the Scottish Highlands and of the Appalachians, which in remote ages excelled the Alps in height, are now carved out by erosion from synclinal strata, a form of struc-

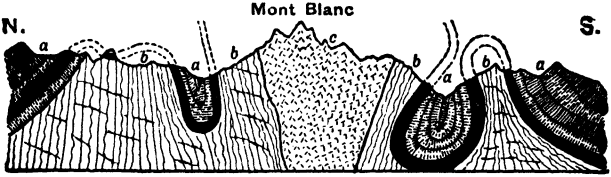


FIG. 49.—Section of the Alps. *a*, Tertiary rocks; *b*, secondary and primary rocks; *c*, central core of schistose and igneous rocks.

ture which gives great stability, like a pile of saucers set one within another right side up.

Theories of Mountain Origin.—The theory most generally held is that horizontal strata, subjected to great thrusting stresses, have wrinkled up along a line of weakness in the Earth's crust, by which the whole crumpling is confined to a narrow area, the actual lifting power being derived from the contraction of the heated interior of the Earth. Mr. Mellard Reade brought forward another theory of great ingenuity. Observing that all mountains of elevation are of comparatively recent formation, and are ridged up out of thick sheets of sedimentary rock, he supposed that the accumulation of sediment produces the mountains. He pointed out that if a large and deep hollow in the Earth's crust is filled up with sediment to the line AB (Fig. 50) at the ordinary surface temperature, say 60°, the mass now forming part of the Earth's crust will grow warmer until, if the surface temperature remains at 60°, that at a depth of 1,200 feet at 80°, and so on (dark lines in figure), the covering in of the cavity raises the temperature throughout by preventing the loss of heat through the crust, the new positions of the temperatures of 60° and 80° being shown by fine lines in the figure. The warmed up strata necessarily expand, and as they cannot expand sideways or downward on account of the solid walls of the depression, they must expand upward, and the surface of the sheet of sediment is thrown into a series of ridges, true synclines and anticlines, like the surface of a cake as it rises in being baked. Professor Reyer supposes that the gliding of rocks from a region elevated in this way leads to folding of the strata and the formation of mountain ranges.

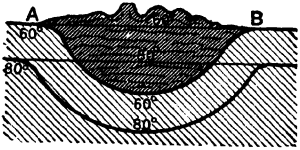


Fig. 50.—Mellard Reade's Theory of Mountain Building. Light shading shows original crust of the Earth, dark shading sediment; dark lines original isotherms, fine lines isotherms after deposition of sediment.

Books of Reference.—See end of Chapter XV.

CHAPTER XIV

ACTION OF WATER ON THE LAND

Land Sculpture.—The crests of the World Ridges upheaved by the internal energy of the cooling Earth, whether in abrupt fault scarps or in gently undulating strata, or in the sharp broken anticlines of mountain ranges, are subjected to erosion by solar energy acting through various agencies. Earth energy may be viewed as continually at work raising, on the whole, the level of the elevated half of the globe, and depressing the Abysmal Area. Sun energy acts as a leveller, continually cutting down the high places and building up the hollows with the resulting detritus or broken fragments. The process of uncovering old rocks by the erosion of newer ones is termed *denudation.* The rate at which it proceeds depends to a very large extent on the chemical composition of the rocks, on their tenacity, their dip, and joints, and it is to the variety of these conditions that the great diversity and distinctive character of the existing scenery of every part of the world is due.

Work of Direct Sun-heat.—One unit of heat when absorbed by one pound of an average rock raises its temperature about 4°, compared with 1° in the case of water. In consequence of this low specific heat, although the heat does not penetrate far, it greatly warms and expands the superficial layer. At night the temperature falls quickly by radiation, and the chilled rock contracts. In dry tropical regions, especially in mountains, the alternate heating and chilling causes the surface layers to split off in angular pieces or thin sheets, which, when the face of the rock is steep, slip down toward the base and form a talus or scree.

Work of Wind.—Air in motion is a powerful vehicle of energy for eroding rocks, sweeping away the fragments loosened by sun-heat in the tropics, and keeping the hard rock surface exposed to destructive radiation. Parts of the Sahara and some other deserts bear traces of having once formed the beds of shallow seas, so that their sand is partly of marine origin; but the amount of sand is always increasing by wind action. Clouds of sand, driven by the wind like showers of hard angular hailstones against the face of the bare rock, cut into the surface as the artificial sandblast etches glass. In Kerguelen, situated in the Roaring Forties, all the exposed rocks are chiselled into grooves from west to east by wind-driven sand. Dunes, or slowly moving sandhills, are formed by the wind on deserts or sea-margins. They may be as much as 60 feet high round the North Sea, and even over 600 feet in the Sahara, but the characteristic form is the same everywhere. They often encroach on fertile country, grain slipping over grain in the direction towards which the prevailing winds blow; but their movement may often be stopped by the growth of grass or other vegetation on the surface. The Bermuda Islands owe their configuration entirely to dunes of coral sand, some of which are 250 feet high, and have been hardened into limestone by the percolation of water.

Wind-borne Deposits.—Sand driven by the wind is an important ingredient in deep-sea deposits, and rivers flowing across arid regions are kept charged with sand and dust in the same way. When the prevailing wind blows inland and the rainfall is scanty, sand and dust may be carried far before being deposited. The remains of many ancient cities in Egypt, Mesopotamia, and Central Asia have been covered by such dust, and their sites are now uninhabited deserts. The name *loess* is given to a deposit of firm unbedded soil, which retains a vertical face when cut down by a stream. It was found first to the north of the Alps and amongst the Carpathians, where it often fills up valleys and covers large areas of ground at various levels. It is abundant at the eastern base of the Andes in Argentina, and still more so in the north of China, where it covers thousands of square miles as a dense yellow earth to the depth of more than 1,000 feet. The loess of Europe and of North America (Mississippi basin) is believed by most geologists to be the sediment of the greatly swollen rivers of the glacial period, subsequently modified by wind and other agencies. The great German geographer, Professor von Richthofen, who studied the deposit in China, came to the conclusion that there it resulted from the gradual accumulation of the fine dust carried by wind from Central Asia, and brought to the ground by the moister air near the coast.

Water as a Sculpture Tool.—Water is the agent by which the Sun's energy is usually brought to bear upon the land. The process consists in the Sun's heat evaporating the surface of the hydrosphere and depositing it as snow or rain on the high land. The work done against gravity in raising water-vapour to the height at which it condenses to the liquid state, as rain, is converted into potential energy, all of which would be restored in heat to the hydrosphere if the rain fell without friction back to the sea again. Rain evaporated before it reaches the sea has a new store of potential energy imparted to it, like a clock wound up before it has run down. The height to which a quantity of water is raised by the Sun's heat is a measure of the power which the water can exert in its descent. This power in the case of raindrops is expended in heating the air they fall through, and in friction against the channel down which the water flows, in breaking off portions of rock against the power of cohesion, and in dragging stones or gravel along. The expended energy finally takes the form of diffused heat in the water and rocks. The chemical properties of water and its effects as a solvent are also brought into action by sun-heat, which separates it from the salts in the sea, shakes it with the gases of the atmosphere, and pours this powerfully solvent and oxidising solution over the rocks. The hydrosphere might be compared to a beehive, whence the sunlight attracts swarms of workers in the form of raindrops, which after a longer or shorter journey return laden with spoil from the land.

Weathering.—Rain, assisted by the dissolved gases and surrounding air, acts chemically on rock surfaces, producing changes known as weathering. Next to beds of rock-salt and gypsum (calcium sulphate), limestone is the rock which is dissolved most readily. The waste of the hard and massive surface is often shown only by the way in which it becomes studded with less soluble nodules or fossils originally hidden in its substance. Sir Archibald Geikie calculated that by the acid-laden rain of towns one-third of an inch is removed from the surface of marble monuments in a century. Insoluble sulphides, such as that of iron, are rapidly oxidised by air in the presence of moisture to form soluble sulphates, and when this process goes on in the pores of a rock, the expansion of the crystallised salt splits the block into thin layers. This action is the basis of the common way of making alum. In the case of granite and most other rocks the process of weathering is more complicated. Some of the minerals are decomposed. In felspar, for instance, the silicates of potash, soda, and lime are changed to carbonates, which are washed away, while the silica and the more resisting silicate of alumina remain as a soft crust of kaolin or china clay, valuable for making porcelain. Granite has been found weathered in this way in South America to the depth of 300 feet. Rocks containing iron usually become brown or reddish in colour, on account of the formation of oxides by exposure to the air, although the freshly broken rock may be white or grey. The lines of stratification and joints of rocks are sometimes etched out by weathering, so that the face of a cliff assumes the appearance of a gigantic wall of masonry. The crumbling of rocks in rainy regions is assisted by the action of the Sun in drying and warming the surface, which may then be splintered into flakes by a shower of cold rain. Rain soaking by capillary attraction through the weathered crust and into the pores of the solid rock is frozen in cold weather, and the ice, expanding as it forms, acts like a multitude of minute wedges driven simultaneously in all directions. When the thaw comes, the bases of cliffs and banks are strewn with weathered crusts and stones, often of a great size, broken off in this way.

Land Waste.—As the result of weathering large quantities of broken material accumulate on all rock slopes and continually slip downwards, becoming more broken-up and smaller as they proceed. The downward movement of stones takes place most rapidly in river-beds where running water aids gravity in carrying them along; but the process goes on even where there are no rivers, and there is a steady downward creep of surface particles even on arid hillsides. Every great line of cliffs is bordered at the base by a steep slope of stones and soil, the angle of which is maintained as long as the supply of material at the top continues. The angle of repose of loose material is attained in a scree or talus, and is such that any additional weight upon the surface causes it to slip. Hence it is dangerous for a climber to ascend or even to pass along the face of such screes as those which form the eastern side of Wastwater in Cumberland or the southern side of the Pass of Brander in Argyllshire. Rain and the wash of temporary torrents help to spread out the lower slopes of screes into the gentler alluvial fans familiar on the flanks of every mountain, and these fans pass imperceptibly into deltas when the place of a temporary torrent is taken by a permanent stream.

Soil.—Weathered rock is the basis of soil, which accumulates to the greatest depth on level or slightly-inclined land. When the rocks yield only angular grains of quartz or silicates, the soil is pure sand, which allows water to drain away so rapidly that in a dry region no moisture is retained. When only the finely divided silicate of alumina results from weathering, the soil is a pure clay, forming when wet a sticky paste through which water does not easily pass. In rainy places clay land is consequently always wet and stiff. Sand and clay are both produced from the decay of most rocks, and the mixture forms *loams*, which are either moderately porous or moderately retentive of moisture. It has been calculated that sand contains about 200,000 particles in a cubic centimetre, loam about 9,000,000, and clay as many as 59,000,000,000. Almost all rocks contain some carbonate of lime, iron, and sulphates or phosphates of the alkalies potash and soda, all of which form part of the resulting soil. Rain contributes salts of ammonia, partly derived from the air, partly from decomposing animal matter, and these are ultimately oxidised to nitric acid, which forms nitrates. Plants pulverise the rock fragments of the lower layers or subsoil by their roots penetrating the crevices and acting as wedges and thus opening passages for the absorption of air and water. The decay of vegetation finally produces vegetable mould. Earth-worms have been shown by Darwin to assist in the formation of soil by dragging decaying vegetation into their burrows and by swallowing the earth, which is thrown out again on the surface as extremely finely-powdered worm-castings. Livingstone had previously pointed out that a similar service is rendered by the termites or white ants of tropical Africa.

Work of Rain.—Rain is the chief agent engaged in the slow but continuous moving on of particles of broken-up rock-crust and soil from high ground to low ground, and from low ground to the sea. When rain falls on beds of clay or soft rock mixed up with harder pebbles or boulders it washes away the softer material, except where it happens to be protected by a stone, which in course of time remains capping a pedestal. The largest examples of such earth pillars are those of the Sawatch region of North America, which attain a height of 400 feet. Mount Roraima, in north-eastern South America, a nearly perpendicular mountain of soft sandstone capped with hard conglomerate, and rising 5,000 feet above the plain, is believed by Sir Everard Im Thurn, who first succeeded in reaching its summit, to be simply a rain-wrought earth pillar on a gigantic scale; the soft sandstone, when freshly exposed, being rapidly washed away by the torrents of one of the rainiest regions of the world, while the harder conglomerate resists erosion and protects the rock beneath.

Underground Water.—Of the rain which falls upon the surface of the Earth a considerable portion returns at once to the air by evaporation, the largest amount runs off over the surface, but a substantial quantity sinks into the ground. Where the rocks are impermeable by water, such as shales and stiff clays, or the surface slopes steeply, more flows off, but where they are permeable, like sandstone, gravel, or many limestones, or the slope is gentle, a greater proportion soaks through. The movement of water underground is slow or rapid, according to the facility with which the rocks allow it to work its way through them. In time some water undoubtedly filters downward, until, under the influence of great pressure and high temperature, it combines chemically with the rock substance, but the greater part of it returns to the surface at a level lower than it started from. Each variety of rock can absorb by capillarity a certain definite proportion of water, which remains in it as in a sponge, until enough accumulates to overcome friction, when it percolates through. The rate of percolation is often greatly increased by the presence of cracks or joints. Soft porous rocks becoming saturated may give rise to landslips, especially in cases where they rest on beds of stiff clay that become lubricated and slippery when wet. As the percolating water dissolves out narrow crevices between the grains of rock, the pressure of the strata above forces them together again, thus producing a slow general settling down of the land-surface.

Wells and Springs.—When a thick layer of permeable rock rests on an impermeable bed, water accumulates until the pressure of the liquid suffices to force a way between the rocks and so reach the surface on the slope of a hill or the side of a valley. This outflow of underground water is termed a spring, and its origin is indicated at *s* (Fig. 51). If a pit is dug through the upper rock, as at W, deep enough to pass below the limit of saturation *l*, water will ooze in from all sides, and a surface well will be formed from which water may be lifted by a bucket or pump. The limit of saturation rises in wet weather, but sinks in a dry season. When it rises from *l* to *l'* the water in the well deepens, when it sinks to the lowest curve shown the well becomes dry, and if the height is not sufficient to overcome the resistance of capillarity the springs also cease to flow. When layers of permeable and impermeable rocks occur one above another, the water which soaks into the permeable rocks at the surface filters down along the junction with the impermeable layer, and if a fissure or fault occurs (*f* in the figure) so that the permeable layer is brought against an

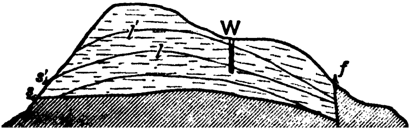


FIG. 51.—The origin of Springs. (After Prestwich.) The darker shading represents rocks impervious to water, the light shading shows permeable rocks. W, a surface well; the curves on the shaded part show different positions of the limit of saturation; s^1 *s*, springs; *f*, fault.

impermeable wall, the water will be forced up along the crack and will reach the surface as a fault-spring if the ground-level is below that of the limit of saturation. Artificial bores driven through an impermeable stratum of rock to reach the water-bearing strata below are termed Artesian wells, from the old name of part of the north of France where they were largely used. By this means a copious water-supply may often be obtained even in rainless deserts, as the deep layer of permeable rock may come to the surface at a great distance in a rainy region.

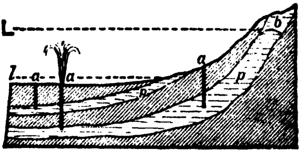


FIG. 52.—Artesian Wells. *p p*, permeable rocks; L, *l*, limits of saturation, showing level beyond which water from the bores *a a a* cannot rise.

Thermal and Mineral Springs.—When the dip of the permeable strata carries them far down into the Earth's crust the water is greatly heated, and if it is brought back to the surface its high temperature entitles the outflow to the name of a thermal spring. Hot springs also abound in volcanic regions and along the slopes of recently upheaved mountains, in which cases they are not necessarily deep-seated. Hot water dissolves much more of the rock substance than cold, and if it has traversed beds of very soluble salts, such as the sulphates, carbonates, or chlorides of the alkali metals or magnesium, it rises to the surface as a mineral spring, often possessed of valuable medicinal properties. The water of deep hot springs frequently exhibits considerable radio-activity to which some of its curative qualities are ascribed. When charged with carbonate of lime, dissolved in the presence of carbonic acid under pressure, the heated water on evaporating at the outlet deposits carbonate of lime in large quantities. Calcareous deposits from such springs often clothe whole hillsides with fantastic sheets of rock, which under the name of tufa or travertine furnish one of the most valuable building-stones in Italy.

Geysers.—Very hot water under high pressure decomposes the silicates in granite and similar rocks, dissolving large quantities of silica, which is deposited as a crust, termed siliceous sinter, when the heated water evaporates on the surface. Some of the most fairylike scenery in the world was formed by such deposits of silica in New Zealand, where the dazzling pink and white terraces near Lake Tarawera were famous show-places until they were destroyed by an earthquake in 1886. Many hot springs depositing silica show the characteristic action of geysers—an Icelandic name expressive of the violent and explosive gushes of steam and boiling water which alternate with periods of quietness. The theory of this action is as follows. At the bottom of the shaft of a geyser the temperature is far above 212°, but the water is kept from boiling by the pressure of the column above and the uppermost layer is cooled below the boiling-point by the air. After a time the surface water gets sufficiently heated from below to begin to boil; this relieves the pressure on the layers beneath which flash into vapour in a series of explosions, throwing up a column of water and steam with a terrific roar. The geyser remains quiescent until it fills up again, when the same process is repeated. In the Yellowstone region of North America the Giantess Geyser throws up a stately column of steam and water 250 feet high in each outburst, after which several weeks of tranquillity elapse; and "Old Faithful," throwing a column of 150 feet, explodes at regular intervals of about an hour.

Caverns.—Since the masses of tufa or sinter formed round hot springs have been taken from the rocks beneath, hollows or caverns must be left in the Earth's crust. These are usually enlargements of the natural crack or fault which allowed the spring to reach the surface. In limestone regions caverns are very numerous and often of great size, on account of the solvent action of rain-water charged with carbonic and other acids percolating through the joints and faults of the strata. The roofs of caverns sometimes sink in, leaving a funnel-shaped hollow on the surface called a sink or swallow-hole, in which, if rubbish blocks up the outlet below, small isolated lakes may form. Such swallow-holes may also form from the surface by the general process of solution and settlement, without the formation of caverns. Part of a cavern roof may remain standing as a natural tunnel or bridge after the debris of the fallen portion has been carried away by rivers. Caverns are usually very picturesque on account of the formation by the dripping water of fantastic stalactites, white or tinted icicle-like appendages of carbonate of lime, hanging from the roof. Where the water drop falls from the stalactite to the floor more carbonate of lime is deposited, and a stalagmite grows upward, and the two ultimately unite to form a natural pillar. Small stalactites formed by the percolation of rain-water through the mortar may be seen hanging from the arches of bridges. The most extensive limestone caverns are those of Adelsberg in Austria, the Mammoth Cave in Kentucky (which comprises more than 150 miles of passages), and the Jenolan Caves in New South Wales. Some of these caverns contain lakes tenanted by blind fish, and underground rivers flow through them. In all limestone regions rivers disappear beneath the surface, and although most of them, like the Guadiana in Spain and the Poik in the Adelsberg caves, reappear on land, several vanish altogether and ultimately well up through the salt water of the sea, sometimes from depths of 100 fathoms or more. These appearances are often spoken of as Karst phenomena, from a district on the coast of the Adriatic where they are highly developed.

Surface Water.—During a shower, and for some time after it has ceased, little runnels of water flow down the steeper slopes of the land, uniting where opposed slopes meet to form streams, which ultimately converge in rivers and flow on to lakes or to the sea. If the land were composed of impermeable rock the whole of the rain-water not lost by evaporation would run off over the surface, and rivers would flow only during and immediately after the fall of rain; this is in fact the case in many mountainous regions where the smooth rock walls are too steep to allow soil to form on them. On gentler slopes the rain first soaks into the soil, and the streamlets swell gradually and are kept flowing long after the rain stops by the subsequent oozing of moisture. Perhaps one-half of the water in large rivers enters them from springs which have pursued an underground course from higher levels, and being independent of local fluctuations of rainfall these give permanence to the flow. When the melting of snow takes place at one period of the year, or when heavy rains occur at definite seasons, the springs are replenished as a store to be drawn on gradually, and the increased supply of surface water produces a regular periodical rise in the level of the river. The Ganges always rises and overflows its banks in summer, when the melting snow of the Himalayas and the rains of the south-west monsoon fill its higher tributaries. Similarly the Nile, after the monsoon rainfall of Abyssinia, overflows its channels in the rainless land of Lower Egypt every autumn, covering a narrow strip on each side with soft and fertile mud. The Amazon, on the other hand, is almost always high, as the rainy seasons of its southern and northern tributaries occur at opposite times of the year with the shifting of the trade winds, but its floods are greatest in June. Sir John Murray calculates that of 29,350 cubic miles of rain falling on the land every year, only 6,520 cubic miles reach the sea as the discharge from rivers, the remainder being re-evaporated or absorbed in the Earth's crust.

River Systems.—The connected streams which unite to form a river constitute a river system. The series of convergent slopes down which a river system flows—in other words, the land which it drains—is called its *basin*, and is separated by a *watershed* or water-parting from the basins of neighbouring river systems. A watershed is always the meeting-place of two diverging slopes. This is sometimes a mountain range, but often only the crest of a gently rising ground, on which the line of water-parting may be difficult to trace. It is usual to name a river system after the river into which the water is collected from the whole basin, the other streams being called tributaries or affluents. The beginning of a river is called its source, and must necessarily be the highest part of its course; but when a river flows from a lake it may be impossible to decide which of the streams entering the lake should be viewed as the ultimate source. The matter is of no real importance, as the only true source of a river is the watershed at which all the tributaries take their rise. The name of the main river in a great system, such as that of the Amazon or the Mississippi, is given by some geographers to the tributary which has the most direct course, by others to that of greatest length or to that with the highest source. This diversity of opinion accounts to some extent for the difference in length assigned to rivers by different authorities. The area of the basin or the volume of discharge is the best measure of the size of a river. It is interesting to notice in the table on next page of the five greatest rivers that although the Nile basin receives one-third more rain than the Mississippi, its discharge is only one-fifth as much, on account of the great evaporation in crossing the desert.

The relation of rainfall to discharge of a river has been very carefully observed in the case of the Thames. On the 3,850 square miles of the Thames basin above Teddington Weir the average annual rainfall is about 28 inches, corresponding to 1,562,800 million gallons or 1·70 cubic miles of water, and the average annual flow, including the water which flows past Teddington Weir and that which is abstracted by the Metropolitan Water Board, is estimated at 500,000 million gallons or 0·55 cubic mile; the loss due to evaporation, percolation into the soil and flow through gravel under the river bed is the equivalent of 19·75 inches of rain over the whole basin, *i.e.* 1,062,800 million gallons or 1·15 cubic mile.

THE FIVE GREATEST RIVER SYSTEMS.

Name.	Area of Basin. Square Miles.	Rainfall of Basin. Cubic Miles.	Average Annual Discharge. Cubic Miles.	Length of Chief Rivers. Miles.
Amazon .	2,230,000	2,834	528	3,060
Congo .	1,540,000	1,213	419	2,900
Nile . .	1,290,000	892	24	4,000*
Mississippi	1,285,000	673	126	4,200†
La Plata .	995,000	905	189	2,000

* Including Lake Victoria and its longest tributary.
† From Missouri source.

Torrential Track.—On account of the forms of the land slopes (see sections of continents, Figs. 58-64) the course of a typical river falls into three natural divisions: the *Torrential Track*, with a slope usually exceeding 50 feet in a mile; the *Valley Track*, with a slope rarely greater than 10 feet, and often less than 2 feet; and the *Plain Track*, in which the change of level is only a few inches in a mile. Some rivers have only one or two of these characteristic divisions. Torrents dash down the mountain-sides with tremendous speed, often exceeding 20 miles an hour, leaping in cataracts from rock to rock and foaming through ravines. Little soil forms on the steep slopes, hence as a rule torrents swell quickly during rain and dwindle to a mere thread of water at other times. The work of a river in its torrential track is purely destructive. When wholly immersed in water, rocks are practically reduced in weight from one-half to one-third, and are therefore moved with much less expenditure of energy than would be required in air. Huge boulders are thus hurled along by the flooded stream, and help to hammer out the hollows in which the water flows. The broken pieces get worn down to form pebbles, gravel, sand, and mud, or, to use a general term, detritus, which is swept away to lower levels. As the ravines are deepened, tributary torrents carve out tributary ravines and the river system gradually entrenches itself in the land.

Valley Track.—The valley track of a river lies over the more gentle slopes that separate mountains from plains, and the velocity of the stream rarely reaches 5 miles an hour, and is usually not more than 2 miles. The work of a river in this part of its course is at the same time destructive and constructive. A stream dashing along at 8 miles an hour can drag boulders 4 feet in diameter; at 2 miles an hour stones as large as a hen's egg are rattled along; at 1⅓ mile an hour the current can just roll pebbles 1 inch in diameter; when gliding at half a mile an hour gravel as large as peas is swept forward; while at a quarter of a mile an hour a river cannot disturb fine sand. In the slackening current of the valley track heavy stones brought down by the torrent cannot be stirred, and the pebbles, gravel, and sand are successively deposited as the slope decreases; and, since a river is retarded by friction with the sides and bottom and flows slowest at the edges, the deposit of stones and sand takes place chiefly at the sides, where they form a shore or terrace. This is the constructive work of a valley river, and the materials of which the terraces are built up are termed alluvial deposits. The stones stranded in these terraces gradually get weathered and crumble to pieces; and during floods the river sweeps away the fragments which are readily broken by friction into sand or mud, and are deposited in new terraces farther down stream. The material swept along the bed of the river acts like coarse sand-paper, scouring the hard clay or rock which forms the river-bed; and as the stream sinks in its deepening channel it leaves its old terraces lining the valley at higher levels. The river also attacks the banks, pressing now against one side, now against the other, undermining cliffs and carrying away the fallen fragments, thus widening the flat bottom of the valley. Other conditions being the same, a valley cut through horizontal strata is equally steep on both sides; but if the strata dip across the stream, the bank toward which they dip becomes much less steep than the other on account of the greater erosive action of springs and percolating rain along the bedding planes.

Plain Track.—On the almost imperceptible slope of its plain track the work of a river becomes entirely constructive. The slowly moving stream is no longer able to carve and commences to model the surface of the land. The alluvial deposits, composed of the finest sands, and finally of mud, assist to raise the level of a wide area as the river wanders over the plain. The alluvial plains of the Mississippi cover 50,000 square miles, a space equal to all England. Remains of dead animals and plants swept away by the river in time of flood become embedded and buried in the alluvial deposits on the margin of rivers or in the mud and sand carried into lakes or seas, where they either decay away or are preserved to form future fossils. The work of a river has been compared to that of a mill which "grinds slowly, but grinds exceeding small," rough angular blocks being supplied in the torrential hopper, and the most finely powdered material poured into the great sack of the ocean.

River Windings.—When a swift-flowing river laden with sediment is checked by any obstacle the sediment is deposited, and a sandbank or mudbank is formed. When an obstruction of this kind is formed on the right bank of a river at A (Fig. 53) the current of the river is deflected from the straight line and strikes against the left bank, rapidly undermining it at the point B, while the velocity of the stream is checked opposite on the right side, which becomes built up by the deposit of sediment. The current is reflected back to the right bank at C, and so the process goes on, until the once straight river forms a series of winding loops as shown by the dotted line. A similar effect may be produced by the unequal hardness of parts of the bank, the softer being worn away and the harder left as obstacles deflecting the current. The windings once begun are perpetuated by

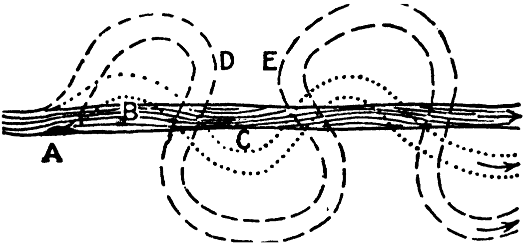


FIG. 53.—Origin of River Windings. A, obstruction on right bank; B, cutting in on left bank; C, resultant cutting on right bank. The dotted broken lines show successive phases of development of windings. The arrows show the direction of the stream.

the set they give to the current always against the concave side, which is made more concave, while the deposit of sediment adds to the convexity of the convex side. As these curves develop they form wider loops (see broken line in diagram) which may approach each other at the points D E. This narrow neck of land may ultimately be cut through by the river, which establishes a short direct passage, leaving an island; or the ends of the cut-off portion may be silted up, converting it into a crescent-shaped lake.

Embanking of Rivers on Plains.—During a flood the swift, muddy stream rises, and, overflowing the banks, immediately widens out on the level land; the current is checked at once, and most of the sediment is deposited close to the banks in the form of broad bands of alluvial soil. When the amount of mud in the water is very great, as in the Mississippi, the Po in Northern Italy, and still more, the Yellow River (Hwang Ho) which traverses the loess deposits of China, the land on both sides of the stream is raised rapidly. The river bed also gets silted up, and the great muddy river ultimately flows along the top of a gently sloping embankment, many feet above the level of the plain (Fig. 54). The natural mud walls, called *levees* on the lower Mississippi, are strengthened artificially in order to protect the dwellers on the fertile borders of the river. Floods frequently make a breach in the wall, and a stream, called a *bayou* in Louisiana, escapes, winding over the low plain, either to rejoin the main river at a lower level or to reach the sea independently. The Yellow River of China has repeatedly changed its course by the high banks bursting. One such disaster occurred in 1852, when the embankments burst about 500 miles from the sea, and the great stream, half a mile wide, formed a new channel, entering the Gulf of Pechili several hundred miles from its former mouth. In 1887 the banks burst again near the same place, leading to the most fatal catastrophe recorded in history, as the river, inundating hundreds of towns and villages, drowned several millions of people.

FIG. 54.—Embankment of a river. B B, original slope of valley. The light shading shows successive layers of deposit; A A, level of river.

Bars, Banks, and Deltas.—When rivers enter a tidal sea directly, the effect of the salt water is to cause a rapid precipitation of sediment, which may accumulate at the mouth of the river and form a bar. Bars are often purely marine formations consisting of shingle or pebbles ridged by the waves, but most of them are due to a combination of river and sea action. When rivers enter a tidal sea by a comparatively wide shallow estuary, such as the Tay, Mersey, or Thames, sandbanks are formed, the size, the position, and shape of which depend on the amount of sediment brought down and the form of the coast-lines which guide the tidal currents. Professor Osborne Reynolds, in a series of beautiful experiments, showed that in a small flat-bottomed model of an estuary, the floor of which was strewn with fine sand, it was possible, by causing mimic tides to stream to and fro in rapid succession, to rearrange the sand in banks with channels between, precisely like those of the real estuary represented. In lakes and seas not subject to strong tides, such as the Baltic, Black Sea, Mediterranean, and Gulf of Mexico, the sediment thrown down by rivers is not swept away, but accumulates like a railway embankment in course of formation until it rises to the level of the sea. The action of waves piles up the deposited mud into low islands on which vegetation takes root and assists to raise the level by forming vegetable mould, These islands split the river into numerous branches. which interlace with one another sometimes in a very complicated way. The typical delta of the Nile originated the name, for below Cairo the river splits into two main branches which enclose a triangular piece of land like the Greek letter Δ (*delta)* in form, the broad growing edge of the delta, 180 miles long on the Mediterranean, being the base of the triangle. The Mississippi delta grows much more rapidly than that of the Nile. It forms a long narrow peninsula spreading out into a series of branches, each traversed by an arm of the river and all constantly varying in size and position. When the amount of sediment is very great, deltas are formed even in tidal seas, as, for example, where the Ganges and Brahmaputra meet at the head of the Bay of Bengal. The Adriatic Sea is being filled up so rapidly by the sediment of rivers descending from the Alps and Apennines that a belt of new land 14 miles wide lies between the present coast and the town of Adria which originally, as a port, gave its name to the sea.

Submarine Canyons.—Mr. J.Y. Buchanan pointed out that along the margin of the Gulf of Guinea the mud brought down by the Niger and the Congo builds up the slope of the transitional area, diminishing its steepness, but that right under the broad, swift, and deep current of the Congo there is a deep submarine gully or canyon, not a submerged river valley, but a furrow walled by the soft mud, and kept clear from deposit by a strong counter-current of sea-water setting along the bottom up the estuary. This counter-current is due to the same cause as that through the Bosphorus (p. 192). Professor Forel believes that a similar sub-lacustrine ravine under the Rhone as it enters the Lake of Geneva laden with glacier mud is due to the sinking of the cold water of the river.

River Work in Dry and in Rainy Climates.—When a river flows across an elevated plateau it wears out a channel for itself, the form of which depends on the nature and arrangement of the rocks and on the rainfall over the surface of the region. In this way very deeply incised features are produced even in cases where no rift-valley or line of faulting has guided the work of erosion. For the sake of simplicity and contrast, it will suffice to refer to the extreme cases of river action on an arid and on a rainy plateau composed of horizontally bedded rocks. In a dry plateau the river flowing from a snow-topped mountain range, over the steepest slope, receives few and small tributaries as it proceeds, and the action of the water loaded with wind-borne sediment is to wear its channel down through the rocks. Cutting now on one side, now on the other, it makes rapid progress through the softer strata, forming banks of comparatively gentle slope, and slower progress through the harder which are cut into steeper cliffs. The walls of the valley retain the original slope as the detritus, instead of accumulating in screes, is swept away as it is formed, and weathering takes place very slowly in the dry atmosphere. The valley becomes eroded in a somewhat V-shaped curve, and forms a gorge, narrow compared with its depth and sunk far below the level of the plain. Such gorges occur on a magnificent scale in the plateau west of the Rocky Mountains, where the most wonderful example is the Grand Canyon of the Rio Colorado in Arizona, about 400 miles in length, and in some parts 7,000 feet beneath the level of the plateau. Seen from above, the steep terraced sides of the canyon show in brilliant tints, sharply visible in the clear air, the whole range of strata as in a geologically coloured relief model. A river flowing over a rainy plateau cannot, save in rare cases, form a canyon or V-shaped gorge because of the number of small tributaries it receives, each of which helps to reduce the slope of the valley walls. The action of rain on the cliffs leads to occasional landslips, forming a gently sloping scree, which protects the lower rocks from erosion and gives the valley a U-shaped section. The valleys excavated across a plateau in rainy regions become wider as they grow older; and according as the rate of denudation over the whole area is nearly equal to, quite equal to, or more rapid than the deepening of the river-bed, the apparent depth of the valley increases very slowly, remains unchanged, or actually diminishes.

Mountains of Circumdenudation.—To a traveller descending the Colorado River the sides of the canyon appear like lofty and precipitous mountain ranges, and where a tributary canyon enters, the appearance of the two meeting slopes is exactly that of a mountain. On the summit instead of a peak there is a vast plateau stretching out as a boundless plain. In a rainy region the valleys of adjacent rivers cut up the plateaux into rounded blocks of elevated land, the exact form of which depends on the composition and arrangement of their rocks. Most geologists believe that the mountains of Scotland, Wales and Norway have been carved out in this way from solid plateaux by the agency of rain, streams, springs, and ice, guided by the durability and structure of the rocks. It is not necessary to suppose that the original plateaux were elevated to their full height before the rivers began to cut them up. The processes of erosion may proceed simultaneously with the process of upheaval, the valley system being hollowed out in slowly rising land.

River Gorges and Waterfalls.—When a river is fairly established in its valley it is the most permanent feature of a land surface in the long geological periods. Upheaval, which acts very slowly, may even elevate a range of mountains across its course, while the river cutting its way downwards remains at the same absolute level. The Uintah Mountains were elevated in this way across the course of the Green River, one of the tributaries of the Colorado. The range in such a case rises divided, like a bar of soap pressed upward against a horizontal wire. Where a river crosses soft and regularly placed rocks its valley is comparatively wide, the sides of gentle slope, and the gradient progressively diminishing down stream; but where a strip of hard rock is encountered the valley narrows into a steep-sided gorge, and the gradient of the river will be suddenly changed. In such circumstances the hard rock is cut through more slowly, and above it the gradient is reduced to what is termed a base-level of erosion, where no destructive action can take place but alluvial deposits are formed. The softer rock farther down stream being eroded more rapidly, a waterfall is formed over the hard ledge, which is worn through in time, and a line of rapids appears in the short portion of steep slope. Eventually the gradient of the whole river bed becomes exactly adjusted to the general slope of the land, and the rapids also disappear. The great waterfall of Niagara is caused by thick beds of hard limestone (black in Fig. 55) resting on soft shale. The river flowing over the cliffs formed by the edge of the limestone cuts away the soft shale from below and so produces occasional slips of the overhanging rock, causing the falls steadily to recede. The falls are now at the head of a gorge 7 miles from the escarpment of the limestone cliff, where the rock is being eroded much less rapidly by weathering. From recent surveys it is stated that the "American" falls have receded 30 feet, and the "Horse-Shoe" falls 104 feet in half a century. If the structure of the rocks is the same all the way, even at this rate the time, geologically speaking, is close at hand when the river-bed will be lowered along its whole length and Lake Erie will be drained. If the Niagara River had been muddy instead of exceptionally clear, its erosive power would have been greater, and the falls would have been worked out long ago. The falls of St. Anthony on the Mississippi, for example, have been cut back about 900 feet since they were discovered in 1680.

FIG. 55.—Ideal Section of Falls of Niagara.

The Work of Rivers and the Geographical Cycle.—From observations of the amount of sediment and of dissolved solids in the water of rivers, it has been calculated that in order to lower the average level of their basins by 1 foot the Danube must work for nearly 7,000 years, the Mississippi for 6,000 years, the Yellow River for 1,500 years, the Upper Ganges for 800 years, and the Po only for 700 years; and at the present rate of surface erosion 4,500,000 years would suffice to equalise the level of land and sea throughout the world. The interaction of upheaval and erosion is expressed in Professor W. M. Davis's theory of a geographical cycle in the life-history of land-forms. He looks on a newly raised plain formed of the stratified waste of an older land as *young*. On a young land surface the rivers flow down the smooth and nearly featureless dip-slope to the sea; but as they gradually entrench themselves and adjust themselves to the land-forms which their own action is bringing into shape, the land eventually becomes *mature.* In a mature land the surface is highly diversified with deep valleys which have adjusted themselves to the general slope of the land and separate well-marked hills of circumdenudation. At a later stage, when the land has been worn down nearly to the base-level of erosion, and forms once more a smooth and nearly featureless surface which Professor Davis terms a peneplain, it is classed as *old.* Remnants of hard rocks may be left projecting as isolated mountains on the peneplain. The rivers flow feebly across the nearly level surface which they are no longer able to erode, and they continue merely to build up the sea margins with their sediment to form low land. A fresh uplift of an old land rejuvenates it, starting once more all the activities of the rivers, and a fresh adjustment of the river valleys to the land in a new cycle is begun.

Lakes are bodies of water occupying hollows of the land. As contrasted with rivers they are transitory features of a region, being subject to considerable fluctuations in extent and destined ultimately to disappear. Lakes often originate in the obstruction of a river valley. If blocked at a narrow gorge by drifting ice or an avalanche the river-bed below runs dry, and the water above rises, flooding the valley, until it reaches the lip of the ice-wall. Ultimately the pressure of the accumulated water bursts the ice-barrier, and a terrific flood suddenly desolates the valley below. The famous parallel roads of Glen Roy in Scotland are believed to be beaches etched out at successive levels by the water of a glacier-obstructed lake, the barrier of which gave way in successive steps separated by long intervals of time. A landslip, the melting of a glacier, or the flow of a lava stream, sometimes obstructs a valley by forming a barrier of earth, moraine stuff, or solid rock, through which the issuing stream cuts very slowly, and the lake so formed is permanent as far as the observations of a lifetime can discover. Hollows produced by the irregular deposit of boulder clay left by the melting of an ice-sheet form lakes in regions where rainfall exceeds evaporation. Slow upheaval of the end of a valley, subsidence of a plain, or the collapse of caverns, are also methods of lake formation, and the craters of extinct volcanoes often collect a large quantity of rain, forming lakelets with neither inflow nor outflow.

The Caspian Sea is the largest lake. Lake Superior comes next in size and is the largest fresh lake. Lake Baikal, in Asia, at an elevation of 1,360 feet above the sea, is the deepest known lake, the maximum sounding obtained in it being almost 800 fathoms. The highest lake is believed to be Horpa Cho, in western Tibet, 17,930 feet, and the lowest is the Dead Sea, 1,290 feet below sea-level.

Function of Lakes.—When the water begins to flow over a new land surface, either freshly upheaved from the bed of the sea or remodelled by the deposit of boulder clay, it necessarily forms a series of lakelets which overflow into one another by streams. As the river system cuts its channels more deeply the smaller hollows are either drained or filled up, and remain as meadows along its course. The abundance of fresh lakes is a testimony to the comparative newness of the land surface and to the youth of its present system of rivers. A river issuing from a lake cuts down the lip it flows over very slowly, except when the barrier is soft clay, as all the sediment which gives to running water the properties of a file is dropped on entering the lake. Lakes thus act as filters for rivers. The exquisite deep blue colour for which some of the lakes of northern Italy and Switzerland are famous is due to the scattering of light from the fine flakes of mica brought in by glacier rivers and suspended in the water. The fans of alluvial deposit laid down by each inflowing stream grow into deltas; and flat meadows encroach on the water so rapidly that lawsuits are occasionally required to determine the ownership of the new land. When two streams enter on opposite sides of a lake the deltas may unite to cut the lake in half, as in the case of Buttermere and Crummock Water in the English Lake District, or the Lakes of Thun and Interlaken in Switzerland. The silting up of the margins of the Great Lakes in Canada seriously affects navigation. Lakes regulate the flow of rivers by keeping up their supply in times of drought, and checking floods during rain. For example, if a river $\frac{1}{10}$ of a mile wide passes through a lake of 100 sq. miles in area, 10 miles from the sea, and a flood takes place in the upper stream which, if passed on directly, would raise the level of the lower 10 miles by 25 feet, and so produce a disastrous flood, it only raises the level of the lake 3 inches, causing a very slight increase of the lower stream.

Salt Lakes.—In arid regions, where evaporation is in excess of rainfall, rivers flowing into hollows of the Earth's crust may fail to fill them up to the brim, and lakes will thus be formed with no outlet. These are necessarily salt, on account of the evaporation of the river-water, and the salts contained differ from those of the sea (p. 179). Analyses of the water of salt lakes show this to be usually the case; but the salts of the Caspian are very similar to those of ocean water, indicating that it is part of the sea cut off by a geologically recent elevation of the land. Yet its salinity is less than 20 per mille, while that of the sea averages 35. *This is because the shelving shores, and particularly the wide shallow inlet of Kara-Baghas, act as natural salt-pans, evaporating the thin layer of water covering them and causing a deposit of crystalline salt, which is thus being gradually withdrawn from solution, while the evaporation is made good by a continual supply of fresh river-water.* On account of the excess of evaporation the surface of the Caspian is now about 90 feet below sea-level, and its shores form a sunk plain. The Jordan Valley, in an equally rainless region, is a still more remarkable instance of a sunk plain. The Sea of Galilee is a small lake 600 feet below sea-level, and from it the Jordan flows for 100 miles along a great rift-valley (p. 239) averaging 7 miles in width, and enters the Dead Sea at a level 1,290 feet below that of the Mediterranean.

Ice Action.—The snow-fields lying on the high parts of mountain ranges above the snow-line continually increase by the condensation of vapour from the atmosphere. The weight of the mass which is augmented by a fresh stratum of snow each year compresses the lower layers, squeezing out the air, and forming granular ice, each granule being a crystal. Part of the snow on high mountains is got rid of by *avalanches*, or snow-slips, but an excessive accumulation of snow is prevented chiefly by *glaciers* or rivers of ice originating in the snowfields and flowing down the valleys. Although ice is one of the most brittle substances to a blow, a glacier moves as if it were a viscous fluid. The cause of the plasticity of glacier ice is due to its granular structure and stratified arrangement, although the precise mechanism of its movement is not yet definitely established.

Glaciers, although solid, flow like rivers, the centre and surface moving nearly twice as fast as the sides, which are retarded by friction with the valley. Compared with rivers their rate of motion is very slow. The Mer de Glace, the most famous glacier in Switzerland, creeps at the rate of about an inch an hour in the centre during summer, and only half as fast in winter. Some of the great glaciers of Greenland move much faster, advancing from 50 to 60 feet in a day, although 20 feet is a more common rate. The thickness of glaciers in the Alps often exceeds 1,000 feet, and their length averages about 5 miles; the longest is the Aletsch Glacier, which measures 15 miles, including the parent snowfield. The Norwegian, Himalayan, Alaskan, and Greenland glaciers are longer; but the greatest in the world are found in the Antarctic continent, the Beardmore Glacier explored by Sir Ernest Shackleton being 200 miles long and descending 8,000 feet in that distance. As a glacier descends along the valley, stones, clay, and sand, loosened by erosion, fall from the slopes, and rest as huge heaps of rubbish, called *lateral moraines*, along each side of the ice. When two glaciers traverse convergent valleys the lateral moraines on one side of each coalesce to form a *medial moraine* (see Fig. 56) down the centre of the united ice-flow. In time a great glacier carrying the ice of many tributaries becomes roughened with numerous parallel ridges of rock rubbish along its length. The heat of the Sun in summer continuously melts the ice, except where it is protected by the overlying moraines, which thus stand out prominently on the surface. Isolated blocks of stone similarly protect and remain perched on ice pillars, while the general surface is being lowered. As a glacier forces its way along an irregular valley the ice is severely strained, and cracks or *crevasses* result, which are narrow and close at first, but gradually widen out in consequence of the centre moving more rapidly than the sides. Huge clefts are thus formed, extending through the ice to a great depth, and swallowing up masses of moraine rubbish. Some change in the channel alters

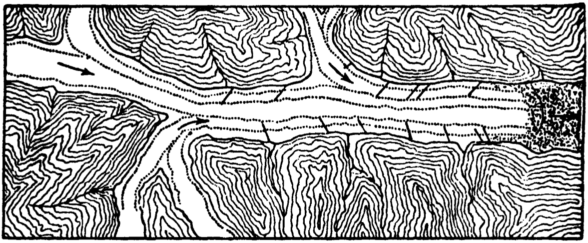


FIG. 56.—Map of a Glacier showing the formation of medial moraines, by union of tributary glaciers. The arrow shows the direction of flow, and the lines radiating from the edges represent crevasses.

the stresses, and as time goes on the old crevasses close up and new ones open. The regions where glaciers occur are shown on Plate VII.

Glacial Work.—Glaciers work both by transporting the moraine material that falls upon them and by eroding and polishing the rocks they pass over. Moraine rubbish falling down crevasses gets wedged in the ice, which presses the angular stones firmly against the bed-rock as the glacier slides forward, the action resembling the cutting of glass by a diamond. Immense quantities of sand and clay result from the grinding down of rock and stones, and are carried along the bed of the glacier, forming the *ground* or *bottom moraine* or boulder clay. When the climate grows warmer or the snowfall diminishes, as that of the Alps has been doing during recent years, the glaciers melt away at the lower end, which shrinks up the valleys, while the boulders which may have been carried far by the ice are deposited on the slope amongst rocks, it may be, of an entirely different nature, and sometimes in very precarious positions. Such travelled and perched blocks are called *erratics*, or simply boulders. The rocks of the valley uncovered by the ice are seen to be deeply grooved or striated by the stones dragged over them, the run of the striæ showing the direction in which the glacier was moving. The surface scratched by sharp stones is at the same time finely polished by the clay, and thus acquires a highly characteristic appearance. The general aspect of the smoothed and rounded rocks is supposed to resemble the backs of sheep, hence the peasants named them *roches moutonnées*, *i.e.* sheep rocks. The stones which took part in the polishing action, and remain embedded in the clay, are themselves scratched and smoothed in a similar way. The descent of a glacier in a steep valley is believed by some students of glaciers to give it an impetus which causes the mass of ice to dig like a gouge when it enters suddenly on flatter ground. To this gouge action, strongest at first, and then gradually diminishing, the peculiar form of the rock-basins of alpine lakes and fiords has been ascribed. The deep weathered crust which forms on granite and other hard rocks is readily scooped out, and its presence doubtless helped in the formation of deep rock-basins. Some geologists are vehemently of opinion that the main effect of glaciers is to protect the underlying rocks from erosion under a blanket of boulder clay, the friction of which may polish the surface but does not excavate any material. When the climate admits of glaciers reaching the sea they give rise to icebergs, and these floating away distribute their deposits far over the bed of the ocean. At the end of a glacier on land the ground moraine forms a ridge of boulder clay, and the various moraine heaps carried along by the ice are thrown down above it, producing what is called a *terminal moraine.* A diminishing glacier in a climate that is growing warmer strews the whole valley, up which it has retreated, with consecutive terminal moraines made up of low hills of detritus, of so characteristic a form that their appearance in a country where no glaciers now exist is positive proof that they were once there. From the melting end of a glacier a rapid stream of ice-cold water flows away, milky with mud, which imparts to it great erosive power. The amount of sediment removed by the Isortek River in Greenland from the base of its parent glacier is calculated at 4,000,000 tons a year.

Rock-basins are usually long and narrow, and attain a maximum depth, often of several hundred fathoms, at a point about one-third of the distance from the head of the basin, as shown in Fig. 57. The lakes occupying rock-basins are characteristic of the valleys on the lower slopes of all mountains which once bore great glaciers. By subsidence of the coast-lands they form fiord-basins filled with sea-water. On the west coast of Scotland Loch Morar, a fresh-water lake 178 fathoms deep, with its surface 30 feet above sea-level, is connected with the sea by a short river. Loch Etive, exactly similar in configuration but filled with sea-water, and only 80 fathoms deep, has its sill so near the surface that, although it is in free communication with the sea at high tide, the current rushing out at low tide forms a veritable waterfall. Loch Nevis, with a depth of 70 fathoms, has its sill 48 feet below the surface. These three cases illustrate the effect of different degrees of submergence on features formed when the land level was higher.

FIG. 57.—Section of Loch Goil, a typical rock basin, the slopes exaggerated 10 times. The upper line shows by its varying thickness the true slope of the bed of the basin.

Ice-caps.—In very cold climates, where the snowline (p. 117) approaches sea-level, the whole surface of an extensive region may be covered by snow to such a depth that it is compacted into ice, filling up all the valleys and standing high over the mountains; such a covering is called an ice-cap or an inland-ice. Greenland is covered with an ice-cap presenting a shield-shaped surface, which Dr. Nansen, who was the first to cross the peninsula in 1888, found to be about 10,000 feet above sea-level, and nearly flat in the interior, sloping rapidly to the sea on each side. The weight of this shield of ice is always squeezing out its edges in the form of glaciers to the sea, and there is probably a constant though very slow outward movement of the ice from the centre over the hills and valleys of the deeply buried land. The Antarctic continent appears to be covered with a far more extensive ice-cap, the top of which forms a vast plateau more than 10,000 feet above sea-level, from which gigantic glaciers descend through steep valleys between the mountains which border the Victoria Land side of the plateau. The snowfall of the region probably does not exceed a few feet in the year, and it is probable that at the present time more snow is carried off the surface by wind than falls upon it from the air, the thickness of the snow-cap and the length of the glaciers which discharge from it apparently diminishing from year to year.

BOOKS OF REFERENCE

See end of Chapter XV.

CHAPTER XV

THE RECORD OF THE ROCKS

Looking Backward.—Two opposed agencies now at work on the Earth's surface—internal energy ridging up the crust, and solar energy cutting down the heights—are sufficient, if they have been long enough in action, to account for all the features of the land. The Uniformitarian school of geologists held that the Earth attained its present condition after passing through vast ages of change so slow as to be almost imperceptible. Another school, called that of the Catastrophists, affirmed that the processes at work in past time were quite different from those of the present, being much more violent and uncertain in their action. Catastrophists looked on valleys as rent in the solid rock by Earth movements, and on mountain ranges as elevated to their full height in a single stupendous heave of the strata. Erosion was considered by them as trimming off the broken edges, as a plane smooths down the signs of the rough rending of a saw. Modern research shows that the truth lies between the two extremes. The Earth, like any other cooling body, must be cooling less rapidly as its temperature falls. When the crust was first formed its high temperature must have considerably increased the erosive power of water. So, too, tidal friction, now insignificant, must once have been a much more powerful agent in shaping the surface (p. 71). Thus, while the processes at work have been always the same in kind as the Uniformitarians claimed, the energy available for the work in a given time was once much greater than now, as the Catastrophists held. Arguments based on the evolution of different forms of life suggested that thousands of millions of years must have elapsed since the Earth cooled down sufficiently to make life possible. Arguments based on the rate of cooling of volcanic rocks suggested that not more than 100 million years were available for all changes; but recently the possible action of radium has been recognised as depriving this argument of its force and most geologists now incline towards the earlier view of the very high antiquity of the cool Earth's crust.

Reading the Rock Story.—If exactly the same areas of the Earth's surface were always subject either to elevation or depression, we could not discover from the rocks laid bare on the surface any record of the process of their formation, for the sedimentary rocks would remain in the subsiding hollows, the older layers being successively covered by newer ones. But it happens that the margins of the world ridges on which sediment is deposited are subject to frequent elevation and depression, and the sedimentary rocks which are exposed bear traces of these changes which it is the special study of geologists to interpret. Where rocks are very much crumpled and folded, it may even happen that the strata have been inverted, the bottom bed of a series having been folded back above the upper beds. When a stratum occurs resting on a different sort of rock, which dips in a different direction or bears signs of ancient erosion, the two are said to be *unconformable*. This structure is clearly indicative of some time having elapsed after the formation of the older series, and before the accumulation of the overlying younger beds. The stratified rocks are like the sheets of an unbound book, some of which have been printed over a second time with a later part of the work; many have been crumpled, torn, and rubbed so that they are illegible; the numbering of all the pages except the last one has been destroyed, and there are evidently places where several pages together have been dropped out. By reading the legible portions of such a book one could find hints of the development of events if the mutilated work were a history, or of the unfolding of the plot if it were a novel. A few consecutive pages found in their proper order would give a key to arranging the rest, and although uncertainty as to the precise sequence of some parts of the narrative might remain, the patient reader could in time obtain a fair idea of the contents. If it is possible to find a narrative showing a regular development of events written on the sheets of rock, in characters with which we are familiar, the order and circumstances in which these rocks were formed can be got at, however confusedly they may now lie. Just such a story is recorded in the Earth's crust, for the sedimentary rocks are full of picture-writings giving the history of successive races of living creatures, and the writings are very legible, being the actual mummies or casts of the creatures themselves.

Fossils.—All remains and traces of living creatures preserved in rocks are called fossils. Some of the traces are only footprints, or worm tracks that have been impressed on an ancient surface of clay or wet sand, and after hardening have been filled in by finer sediment. Plants and animals are usually represented only by their hardest parts, such as bark, shells, teeth, or bones. But often the whole organism was surrounded by compact sediment, in which, as it decayed away, a hollow was left exactly corresponding with its outer surface. This mould became filled in turn with fine sediment, or impregnated with carbonate of lime or silica deposited from solution in the water which percolated through, and thus a perfect cast or model has been produced. The most complete fossils preserve not only the external form but the minutest internal structure, every part having been individually turned into stone by the exchange of animal or vegetable substance, molecule by molecule, for some mineral such as pyrite (sulphide of iron), calcite (carbonate of lime), or one of the several forms of silica. Other fossils are simply shells or skeletons closely compacted together, such as chalk, made up of foraminifera like the deep-sea oozes (p. 224), coral limestone (p. 228), and siliceous earth composed of the cases of diatoms. Sometimes organic substance undergoes only partial decomposition while retaining much of its original form. Coal, for example, is the residue of partially decomposed vegetation.

Interpretation of Fossils.—As a general rule it is assumed that the creatures whose remains occur in the rocks were similar in their habits to those now living, and were in an equal degree dependent on the climate. Rocks formed of the sediment of lakes and rivers may, by the greater abundance of land creatures amongst their fossils, be distinguished from those composed of marine deposits. These inferences are often confirmed by the nature of the rocks themselves, the fine mud of estuaries naturally yielding a shale, while the pebbles of an exposed seashore are compacted into a conglomerate. Rocks containing the remains of the same species of creatures have evidently been formed under similar physical conditions, and possibly at the same time; hence they are said to belong to the same geological horizon.

Divisions of Sedimentary Rocks.—There is so much scope for individual opinion in interpreting the record of the rocks that no minute classification of them meets the approval of all competent geologists, but a few comprehensive divisions are generally accepted. The most ancient sedimentary rocks are allowed to be those containing fossils of none but the simplest forms of life. The variety and complexity of the organisms found usually increase as the more recent strata are approached. The greatest thickness of a bed of sedimentary rock may in some cases give a rough measure of the shortest time it could have taken in formation, but all attempts at fixing a definite geological chronology have as yet been unsatisfactory. The great divisions of rocks now generally recognised and their more important subdivisions are given below in the order of antiquity, and some typical forms of life the remains of which are found in them are mentioned.

QUATERNARY

RECENT—Now forming.
PLEISTOCENE—All modern plants and animals. *Man.*

TERTIARY

PLIOCENE—Most modern plants. *Elephant, Ox.*
MIOCENE—Tropical plants. *Ape, Antelope.*
OLIGOCENE—Tropical plants.
EOCENE—Tropical plants. *Palæotherium, Lemur.*

SECONDARY

CRETACEOUS—Flowering plants. *Foraminifera, Marsupials, Toothed Birds.*
JURASSIC—Ferns. *Saurians, Marsupials, Archæopteryx, Corals, Ammonites, Cuttlefish.*
TRIASSIC—Cycads. *Ammonites, Reptiles.*

PRIMARY

PERMIAN—*Amphibians.*
CARBONIFEROUS—Lycopods. Tree-ferns, Conifers, *Crinoids, Fishes, Amphibians.*
DEVONIAN AND OLD RED SANDSTONE—Lycopods, *Fishes, Brachiopods.*
SILURIAN AND ORDOVICIAN—Sea-weeds. *Graptolites, Trilobites, Fishes.*
CAMBRIAN—*Trilobites, Sponges.*
ARCHÆAN—No forms of life known with certainty.

Older Primary Rocks.—The Primary division is called the *Palæozoic*, as in it the fossils of the earliest living creatures are preserved. The Archæan, which forms the foundation rocks, consists mainly of crystalline schists. Wherever these appear on the surface we know that the land is of extreme antiquity, for it must either have remained above the sea while all the other formations were being deposited elsewhere, or if it was upheaved after being covered with younger rocks, the period must yet be sufficiently remote to have allowed all the more recent strata to be eroded away. No fossils are known with certainty in Archæan rocks. The Cambrian, Ordovician, Silurian and Devonian systems, named after the districts in south-western Britain where they were first studied, were formed in successive periods. Fossils of sea creatures are abundant in these rocks; a peculiar crustacean called the trilobite swarmed in the Silurian seas, and seems to have become altogether extinct before the end of the Primary period. The earliest land-plants, which were cryptogams, leave a record in the Upper Silurian rocks. In the Old Red Sandstone rocks which were laid down as sediment in fresh-water lakes in the Devonian period, fossils of fishes clad in enamelled bone and of scorpion-like creatures appear.

The Carboniferous System is composed of thick beds of limestone, which must have been deposited at the bottom of a clear shallow sea, of sandstones laid down on ancient beaches, and of shales which represent the solidified mud of estuaries. The name Carboniferous comes from the beds of coal which result from the decay of bark, fronds and spores of club-mosses, and tree-ferns of giant size, on the swampy margin of the ancient sea. Clay-beds usually underlie coal-seams, and represent the soil in which the carboniferous plants grew, being often full of the fossil roots. The formation of coal is an interesting example of chemical decomposition. The action of heat and pressure on vegetable matter in the absence of air is to drive out more and more of the oxygen, nitrogen, and hydrogen it contains, combined with very little carbon. The following table gives the average composition (omitting the ash) of dry wood; peat, which results from vegetation decaying in recent formations; lignite, a woody form of coal found in tertiary rocks; true coal; and anthracite, which is apparently derived by heating coal. It has been conjectured that the final product of this process is graphite or the diamond, pure crystallised carbon.

CARBONIFEROUS MINERALS

	Wood.	Peat.	Lignite.	Coal.	Anthracite.
Carbon	50	60	67	85	94
Hydrogen	6	6	5	5	3
Oxygen and Nitrogen	44	34	28	10	3
	100	100	100	100	100

The great limestone beds of the Carboniferous period are composed of the remains of crinoids, mollusca, and many other marine creatures. Amphibians, mostly small, but some of great size, crawled through the marshes, but the only true land animals preserved are of the nature of scorpions, insects, and snails. This period was one of great volcanic activity, and the hard bosses and dykes of volcanic rock exposed by denudation give diversity to the landscape in many regions where carboniferous rocks are exposed.

Newer Primary Rocks.—In the Permian period, named after the Russian government of Perm, where the rocks of this age are greatly developed, plant life appears to have been less abundant and varied than in Carboniferous times, but remains of great amphibians abound, and those of true reptiles appear for the first time. Palæozoic rocks sometimes exert a considerable local influence on a freely-suspended magnet. In the course of a magnetic survey of the British Islands, Professors Thorpe and Rücker found a line of magnetic disturbance extending across the comparatively recent strata of southern England, coincident with a deeply buried mass of Palæozoic formation running from the old mountains of Wales toward the Carboniferous region of the continent of Europe, the existence of which had previously been inferred from geological evidence. In 1890 this conclusion was strikingly confirmed by the discovery of coal in a very deep boring through the secondary rocks of eastern Kent.

Secondary Rocks.—The secondary rocks are termed *Mesozoic*, because they contain evidence of the existence of living creatures intermediate between those of the Primary period and of the present time. In the Trias there are signs of gigantic amphibians, reptiles of the crocodile kind, and of the simplest forms of mammals, the marsupials. The Jurassic system takes its name from the Jura Mountains, and is sometimes known as Oolitic (egg-stone), from the granular limestones resembling the structure of a fish-roe, by which it is characterised. Many beds of limestone of this period are fossil coral-reefs. The most abundant mollusca were the ammonites, with wonderful rolled shells, and cuttle-fishes. Saurians—reptile-like animals—grew in those days to an enormous size, and inhabited air, sea, and land. The Pterodactyls were small reptiles with wings not unlike those of a bat. Ichthyosaurus and Plesiosaurus were swimming reptiles, sometimes 40 feet in length, and the land reptiles were probably the hugest animals that ever inhabited the globe, the remains of the Atlantosaurus, discovered in North America, indicating a length of 100 feet and a height of 30 feet. Archæopteryx, the first bird-like creature, appears in the Jurassic period. The Cretaceous or chalky rocks are largely composed of solidified globigerina oozes, and innumerable shell-bearing sea creatures occur amongst them. Fishes like the herring and salmon appeared for the first time, and huge reptiles and birds with teeth were common. Traces of flowering plants also appeared amongst the prevailing ferns.

Tertiary Rocks.—A great gap generally separates the period of the Mesozoic rocks from that of the *Cainozoic* or Tertiary. During the interval the huge reptiles and ammonites became extinct, and forms of life appeared more nearly resembling those of the present day. The divisions of Tertiary rocks—Eocene, Oligocene, Miocene, and Pliocene — were originally arranged in the order of the abundance of the fossils of mollusca, resembling those now existing. As the period progressed plants and animals which approached more and more closely to those we now know appeared on the Earth. Foraminifera attained a great size and were extremely numerous, one being the large coin-shaped nummulite which makes up many of the limestones. Mollusca like the oyster and snail began to predominate over those of the cuttle-fish kind. Amongst the mammals the marsupials became less numerous, and many transition forms of the Eocene approach the carnivorous type. Later, gigantic ant-eaters, the elephant-like Mastodon, pig-like animals, antelopes, and apes appeared. A succession of animals of increasing size, approaching nearer and nearer the nature of the horse, runs through the series, culminating in the true horses of the Pliocene age. The fossils of these large animals are never so complete as those of mollusca or fishes, some teeth, or a few shattered bones, being all that is sometimes found. The Tertiary period was characterised by great volcanic activity in all parts of the world, and the existing scenery of many lands is due to the effects of denudation on the bosses, basalt sheets, and lava dykes of the volcanoes of that period.

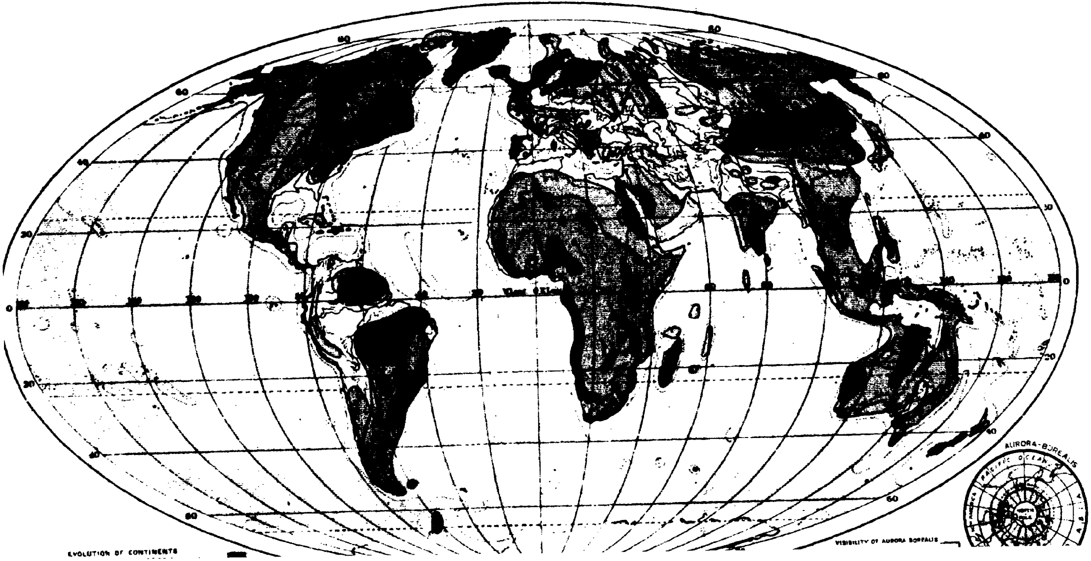
Quaternary Rocks.—The post-Tertiary or Quaternary rocks are the least ancient of all. They are rarely even consolidated, consisting chiefly of clays and sands. The Pleistocene formation in northern Eurasia and America consists almost entirely of boulder clay, the result of ice-action, and the period has been termed the Great Ice Age. Many exposed rock surfaces on the mountain-tops as well as in valleys, in places where glaciers have never been seen, closely resemble the *roches moutonnées* of Switzerland (p. 283). Perched blocks are scattered thickly over all parts of Northern Europe and America, and from their nature many of them are known to be far travelled. The conclusion is irresistible that after the formation of the last Tertiary rocks these lands were subject to ice-action. Great and widespread subsidence, and subsequent elevation of the land, took place during this period. Some writers maintain that the boulder clay, perched blocks, and ice-scratchings were brought about by this subsidence permitting fleets of icebergs sailing southward to strand or rub against surfaces which were afterwards elevated. To most geologists, however, the evidence of true glacier action having occurred over the whole area is overpowering, although the period is so remote that atmospheric erosion has in many cases obliterated the work of ice.

The Great Ice Age.—Glaciation probably occurred on the grandest scale, the ice marching over mountain and valley with little regard to the form of the surface. In the Glacial period it appears that all Northern Europe and Northern America (see light blue tint on Plate VII.) were covered by vast ice-caps, resembling those now overspreading Antarctica and Greenland, which polished and smoothed off the mountains, and swathed the valleys and plains with blankets of boulder clay. The ice is held by some geologists to have spread beyond the margin of the land, to have hollowed out deep furrows across the Continental shelf, and sometimes even to have ploughed up the shallow sea-bed and scattered the sand and shells on the coast-lands. Professor James Geikie discovered that the Great Ice Age was divided into periods during which the climate was very severe, while between them a genial climate prevailed, and interglacial beds of peat were formed containing a varied vegetation and the remains of insects and mollusca. The cause of changes of climate, sufficient to produce such effects, has been the subject of much speculation. The late Dr. Croll, whose theory was once widely received, pointed out that the changes in the eccentricity of the Earth's orbit (p. 75), combined with the precession of the equinoxes (p. 79), must have produced a severe climate in the northern hemisphere at the period when aphelion occurred in the northern winter, and the eccentricity was at a maximum. The objections to this theory are numerous and weighty, and it is now held by few geologists. It is now more usual to explain the cause of the Glacial Periods by changes of climate brought about by changes in the positions of land and water. Some geologists account for the changes of level which undoubtedly occurred during the Glacial Period by supposing that the great ice-sheet depressed the elastic strata by its weight, producing extensive subsidence, followed by upheaval when the ice-cap melted. Others explain raised beaches (p. 234) on the assumption that the land remained rigid and the mass of ice raised the level of the ocean by attraction (p. 207). In the river and cave accumulations of the Pleistocene age the first undoubted signs of the human race appear in the form of coarse chipped stone implements and rough etchings on bone.

Evolution of Continents.—Rocks of Archæan and Palæozoic age cover a greater area on the Earth than those of Mesozoic age, which are in turn more extensive in their distribution than those of the Tertiary system. This shows that more of the elevated half of the globe was covered by the sea, in which sediment accumulated, in Palæozoic than in Mesozoic, and in Mesozoic than in Tertiary times. It is pointed out by Professor J. Geikie that the elevated and depressed halves of the World have been growing more and more distinct throughout geological ages, and as the Abysmal Area (p. 209) has grown deeper and the World Ridges higher the superficial extent of the hydrosphere has been steadily diminishing, although its volume remains the same. This change must be looked on as a general result of innumerable minor elevations and depressions. The following hypothesis of the growth of continents is not to be regarded as an established theory, but as a probable conjecture of the relative order in which the various land-masses were formed. Plate XIV., adapted from Professor J. Geikie's maps, shows in the deepest tint the areas of the World Ridges that are believed (although the evidence is far from complete) to have projected above the hydrosphere during the greater part of the period when Palæozoic rocks were being formed. They composed groups of great islands clustered on the northern and scattered over the southern parts of the World Ridges, between which warm ocean currents would flow from the equatorial seas, and an equable climate would reign over the whole land. In the Mesozoic period the lands (shown in the second tint) were far more extensive, but insular conditions still prevailed. The deepened Abysmal Area drained the oceans from the summits of the World Ridges, and the up-ridging of the Continental Area raised wide tracts far above the sea. The western and eastern edges of the great Eastern World Ridge were clearly outlined, but the sea spread across its central portion from east to west, and from north to south. The Western World Ridge was developed similarly, land extending along its western and eastern edges in North America, separated by a wide sea-channel from south to north, while in the South American portion the central part of the existing continent had appeared running almost from north to south. In the Tertiary period there was an enormous increase of upheaval over the World Ridges, and crests of them (lightest brown on map) everywhere emerged. The sea still swept over the central part of the Eastern World Ridge from north to south and south-west, so that the Indian Ocean was united with the Arctic Sea, and through the wide Mediterranean with the Atlantic. Africa and Australia were almost as extensive as at present. Britain was separated from Scandinavia, and the south of Europe formed a mountainous archipelago, amongst the islands of which the Alps and Balkans were conspicuous. The Indian peninsula was still an island, and the Himalayas were beginning to appear,

EVOLUTION OF CONTINENTS.

After James Geikie.



The Western World Ridge was nearer completion, North America was almost all above water, and the line of the Andes was commencing to give outline to South America. By the close of the Tertiary period the elevation of the continents had been practically completed.

BOOKS OF REFERENCE

Sir A. Geikie, *Text-Book of Geology*. Macmillan and Co. (A complete discussion of Geology from the modified Uniformitarian standpoint, with references to important original papers.)

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CHAPTER XVI

THE CONTINENTAL AREA

Crest of the World Ridges.—(Read pp. 205-209.) The six largest islands or peninsulas in which the crests of the World Ridges break through the uniform covering of the hydrosphere are termed continents, and designated by the names Eurasia, Africa, North America, South America, Australia, and Antarctica. They are distinguished from other islands and peninsulas by size alone, Australia being 3½ times larger than Greenland, and Africa 10 times larger than Arabia, these being the greatest island and peninsula not called continents. The elevated region round the South Pole is crowned by the continent of Antarctica, the area of which cannot yet be assigned. The land mass of Eurasia is conveniently supposed to consist of the two "continents" of Europe and Asia, and if this be allowed, we find that the seven continents group themselves into three pairs and a central one. North and South America share the Western World Ridge; Asia and Australia, on the eastern limb of the Eastern World Ridge, lie diametrically opposite; while Europe and Africa occupy the western limb of the Eastern World Ridge, diametrically opposite the great Pacific basin. Until the Tertiary period, when the heights of Central Asia were upheaved, the Indian Ocean stretched to the Arctic Sea; and even in Quaternary times Europe and Asia were separated by a broad channel of water between the Mediterranean and the Arctic Sea. The prevailing continental form is a south-pointing triangle, the longest side of which runs in a direction a little east of south. In each pair of continents the northern has a wide extension from east to west, a deeply indented coast, and a great group of islands on the south-east stretching toward the unindented coast of the southern member, which, as a rule, extends from north to south, and has an island or island group lying to the south-east.

Comparison of the Continents.—By studying the maps (Plates XI., XII. and XIII.) and the following tables (pp. 302, 303) the student will be able to compare the characteristics of the separate continents, attention being concentrated on the three pairs, as the statistics of Antarctica have still to be determined. The average heights in Table A are those calculated by Sir John Murray, from whose figures also the relative areas at various elevations (Table B) are derived. Professor Krümmel, the eminent German oceanographer, calculated the percentage of surplus coast given in Table A. Since a circle has the smallest boundary of any figure of the same area, if we imagine the coast-line stripped off a continent like braid off a coat, and the continent moulded into a circular outline without change of area, a smaller length of coast would serve to surround it. The length of coast left over is expressed as percentage of the original length, and serves as a measure of the surplus available for bordering peninsulas and bays. In the three northern continents, it will be noticed, more than two-thirds of the coast-line are thus available; in the three southern continents less than one-third. The chief mountain ranges which rise above the snow-line in each continent are marked by red lines on Plate XVIII.; this should be compared with the orographical map (Plate XI.), on which plains and plateaux are more clearly shown. The statistics are only approximate, because sufficiently accurate maps to yield correct measurements for all the continents do not yet exist.

COMPARISON OF THE CONTINENTS

CONTINENT.	Asia.	Africa.	N. America.	S. America.	Europe.	Australia.	All Land.
TABLE A.—AREA, ELEVATION AND COAST-LINE							
Area (million sq. miles)	16·4	11·1	7·6	6·8	3·7	3·0	55·0
Average height (feet)	3,000	2,000	1,900	2,000	940	800	2,100
Highest point (feet)	29,000	18,800	19,500	22,400	18,500	7,200	29,000
Surplus coast (per cent.)	61·7	28·3	64·6	32·6	87·6	30·6	...
TABLE B.—PERCENTAGE OF CONTINENTAL AREAS WITHIN ZONES OF EQUAL ALTITUDE ABOVE SEA							
Below sea-level	1·4	0·1	0·05	0·0	1·8	0·0	0·6
0-600 feet	23·3	12·5	32·25	40·0	53·8	29·8	26·7
600-1,500 „	16·0	34·8	32·1	26·8	27·0	64·3	27·8
1,500-3,000 „	21·7	27·6	13·3	16·8	10·0	4·1	19·3
3,000-6,000 „	21·8	21·8	13·2	7·0	5·5	1·5	17·0
6,000-12,000 „	10·0	2·8	8·4	5·0	1·7	0·3	6·0
Above 12,000 feet	5·8	0·4	0·7	4·4	0·2	0·0	2·6

Continental Slopes. — The simplest conceivable continent would consist of two land-slopes meeting, like the roof of a house, along a central line or axis, so that a section across it would resemble A, Fig. 58. The axis of a continent is usually formed by a mountain range of elevation (p. 252), which most frequently occurs near the edge of the slope of the world ridge, and

FIG. 58.—Typical Sections of a Continent. In B C D the short slope is shown to the left, the long slope to the right.

consequently near one side of the continent, so as to produce a short slope on one side and a long slope on the other, giving a section like B. A mountain chain is rarely single, and is usually about equally steep on both sides. It occupies a narrow strip of a continent; so while the short slope of the continent is nearly uniform to the sea, the long slope is broken into a steep and a gentle portion, giving the section C. But since both sides of a continent have been ridged up, a lower and broken mountain range usually intervenes between the long slope and the sea, converting the central part of the continent into a wide valley, and forming a second short slope to the seaward side, as shown in section D. The various slopes form parts of river-basins (p. 267), and the course of rivers in an ordinary map serves to mark out the direction of the slopes. Where there are no rivers, or when rivers flow into a salt lake, a region of internal drainage results. Such regions occur in every continent wherever the arrangement of the heights cuts off rainfall and allows full scope to the action of evaporation. One-quarter of the Earth's land surface is thus situated. The long slopes of all the continents are directed toward the Atlantic Ocean and its seas, which thus receive the drainage of more than half the land (Plate XIII.). All the continents turn their backs, so to speak, on the Indian and Pacific Oceans. The following table is calculated by Sir John Murray.

PERCENTAGE AREA OF CONTINENTS* SLOPING TO EACH OCEAN

Ocean.	Eurasia.		Africa.	N. America.		S. America.	Australia.	World.	
Atlantic, including Mediterranean	13·9	37·9	49·0	36·0	76·5	86·4	...	34·3	50·8
Arctic Sea	24·0		...	40·5		...	...	16·5	
Pacific . .	19·6		...	20·3		6·3	9·3	14·4	
Indian . .	15·3		20·0	...		...	40·0	12·8	
Inland . .	27·2		31·0	3·2		7·3	50·7	22·0	
	100·0		100·0	100·0		100·0	100·0	100·0	

* Omitting Antarctica.

The small area draining into the Southern Ocean is added, in the table, to those of the Atlantic and Pacific Oceans, but Antarctica is not included.

South America being the most typical continent may be first described. The triangular outline is modified by a large outcurve of the northern half of the west coast north of 20° S., and on the middle of the east coast by a more prominent outcurve culminating in Cape San Roque. Its greatest length, nearly along the meridian of 70° W., is 4,800 miles, from Point Gallinas on the Caribbean Sea in 13° N. to Cape Horn on the Southern Ocean in 56° S., the Fuegian islands being considered as part of the continent. The greatest breadth from west to east is 3,300 miles along the parallel of 5° S., between Point Parina (82° W.) and Cape San Roque (35° W.). A group of rocky islands, the Chonos Archipelago, runs for 1,200 miles close to the fiord-grooved west coast at its southern extremity, and a tortuous channel separates the south-eastern tip, Tierra del Fuego, from the mainland. The average elevation of the continent is almost exactly that of the whole continental area.

The Andes.—The main axis of South America lies close to the west coast along the crest of the Andes, which form the longest mountain system, unbroken by passes of low elevation, in the world. The short slope to the Pacific varies from 30 to 150 miles in breadth; the long slope to the Atlantic is in parts 3,000 miles wide. A mountain system is not a ridge, but a region showing diversities of structure and scenery from point to point. The highest peak of the Andes is Aconcagua, 22,400 feet, in 33° S.; but at least thirteen other summits rise more than 19,000 feet above the sea. Many of the passes, which mark the meeting of the heads of transverse valleys of opposite slopes, are elevated more than 14,000 feet, and the lowest in a stretch of 4,000 miles is 11,400 feet above sea-level. Tertiary sedimentary rocks form the slopes of the Andes, and are overspread in many places by sheets of volcanic rock, while the loftiest volcanic cones in the world shoot up in solitary grandeur above the ridges. The Andes are young mountains, geologically speaking, and are still growing. Every little step of upheaval is accompanied by earthquakes, which occur more frequently along the western margin of South America than anywhere else. South of Aconcagua the system consists of a single rugged ridge, which gradually diminishes in height and in steepness toward the south, where the sea has invaded its valleys forming the Chonos Archipelago. From Aconcagua northward to the equator the system forms two mountain ranges, one keeping close by the Pacific coast, the other sweeping inland. Where they diverge most widely the two mountain walls encircle a high plateau of internal drainage, which is as large as Ireland, and its lowest part, 12,000 feet above the sea, is occupied by the great Lake of Titicaca. Converging at the northern extremity of the Titicaca Plateau the two ranges wall in a longitudinal valley of great length, sloping northward and traversed by rivers which escape by wild gorges through the eastern ridge. From the equator northward the ridges of the Andes diminish in height, unite in the "Knot of Pasto," and then branch into three spurs, separated by the long valleys of the Magdalena and Cauca sloping to the north. The eastern spur sweeps round the north coast of South America, completing the framework of the continent. Along its whole length the eastern ridge of the Andes slopes down eastward to the central low plain by a succession of great terraces, and sends out many short diverging mountain buttresses. Ores of silver, mercury, and copper abound in these mountains, and coal-beds occur in the south. On the rainless western slope in the centre nitrate of soda forms extensive deposits.

Eastern Mountains and Low Plains.—The long slope of South America from the base of the Andes forms one vast low plain stretching from north to south, the portion of which, at a less elevation than 600 feet, is equal to two-fifths of the continent. It is broken into three divisions by two very gentle ridges stretching eastward from the Andes. The northern and smaller swells up into the *High Plain of Guiana*, which is cut into lines of heights, known as the *Sierra Parima*, the *Sierra Pacarai*, culminating in Roraima (p. 261), and the *Sierra Acaray*. The larger or *High Plain of Brazil* fills the whole eastern outcurve. It is an upheaval of very ancient rock, which has been cut by the valleys of numerous great rivers into a medley of mountain masses, few of which exceed 3,000 feet in height. The *Sea Range*, under many names, runs along the coast from 10° S. to 30° S., forming the steep seaward slope of the High Plain. The eastern mountains contain deposits of gold and of diamonds, and are covered in many parts by fertile soil. Fig. 59 gives an idea of the form of the slopes of South America on the parallel of 18° S.

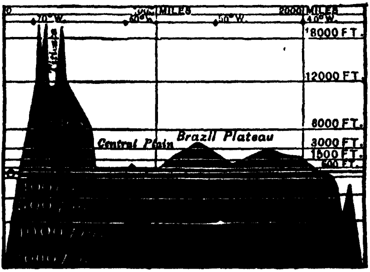

FIG. 59.—Section across South America on parallel of 18° S. Vertical scale 300 times the horiontal. Sea-level marked O.

Orinoco Basin. — The northern division of the Low Plain is known as the *Llano*, and forms the basin of the Orinoco River, which is kept supplied with water by tributaries descending from the mountain borders. The Orinoco, from its source on the south-west of the Guiana High Plain, flows along the watershed which parts its basin from that of the Amazon. One branch, retaining the name Orinoco, eventually flows down the northern slope and sweeps east to the sea, while another, known as the Casiquiare, breaks away down the southern slope and flows rapidly into the Rio Negro, a tributary of the Amazon. The two great river systems are thus connected by a natural canal.

Amazon Basin.—At a distance of 1,900 miles from the Atlantic the vast central plain only reaches an elevation of 600 feet, and the basin of the Amazon presents the gentlest land-slope in the world. On each side the Amazon and its tributaries overflow in the rainy season (p. 266), covering the land for 20 or 30 miles from the banks, and depositing fine alluvial soil which, over the whole region, does not contain a stone as large as a pea. Numerous great tributaries, many exceeding 1,000 miles in length, converge to the main river from the slopes and high valleys of the Andes. Of these the Maranon is generally considered the head stream, although the Ucayali is longer. Other rivers flow in, like veins joining a leaf-stem, from the Guiana High Plain in the north and the Brazil High Plain in the south. Two of the largest rivers of the latter region flow north in wide valleys but do not reach the Amazon: one, the Tocantins, enters the sea close to its mouth, and the other, the Rio San Francisco, curving sharply to the east, reaches the Atlantic about 10° N.

La Plata River System.—From the temporary lake which forms west of the flat, low plateau of Matto Grosso in the rainy season, and gives origin to some of the southern tributaries of the Amazon, the River Paraguay flows south along the low plain, receiving numerous tributaries from the Andes slopes on the west, and the great river Parana from a southern valley of the Brazilian High Plain on the east. The united river swerves eastward and enters the wide shallow estuary termed the Rio de la Plata at 34° S. The undulating grassy plain of its lower track is called the *Pampas*, and is one of the flattest low plains in the world. South of the La Plata several rivers flow from the Andes towards the Atlantic, but some of these dry up on the Pampas and do not reach the sea. All are subject to floods on account of the abrupt change of slope at the base of the mountains, the inclination of the low plain toward the east being too slight to let the water drain away when the torrential track is flooded, Patagonia, the southern extremity of the continent, is in large part a desert of shingle, and much of it is an area of internal drainage on account of the drying up of the rivers flowing from the Andes.

North America presents the typical form and configuration of a continent, but it resembles South America passed through a mangle, being larger, wider, lower, with less contrast between its heights and plains, and a much more broken coast line. Fig. 60, a section across the continent on the parallel of 36° N., and Fig. 61, on the meridian of 90° W. along the central low plain, are on the same scale as that of South America. The total length of the continent, nearly on the meridan of 100° W., is 4,500 miles from the ice-bound Arctic archipelago in 82° N. to the tropical isthmus of Tehuantepec in 17° N. The greatest breadth, on the parallel of 52° N., is 3,000 miles. In the extreme north-west Cape Prince of Wales on Bering Sea comes within 40 miles of the north-eastern extremity of Asia; and on the north-east Greenland is bound to America by continuous

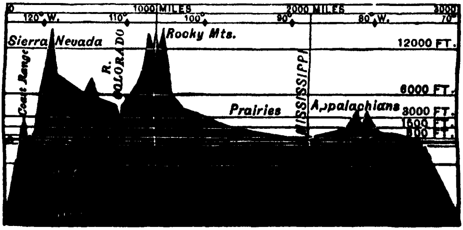

FIG. 60.—Section across North America in 36° N. Vertical scale 300 times the horizontal. Sea-level marked O.

ice in winter. The west coast and northern part of the east coast of North America are high and rocky, but the south-east presents one of the longest stretches of gently shelving shore in the world.

Western Heights of North America. — From Tehuantepec to Alaska the axis of the continent runs, crowned by the *Rocky Mountains*. This range has been considered to be a continuation of the Andes, but it is less lofty, the passes across it are lower, and the two slopes into which it divides the continent are more nearly equal than those of South America. The average distance from the west coast of the range or the eastern edge of the plateau which it outlines is about 400 miles except where the great Pacific outcurve increases the distance to almost 1,000 miles. Mount Brown, near 52° N., is the highest peak, 16,000 feet. One of the grandest portions of the range has been set apart as a permanent museum of physical geography on a grand scale, under the name of the Yellowstone National Park. On the east the Rocky Mountains slope down in wide terraces comparatively gently to the central low plain. On the west their slope is abrupt but short, terminating in a wide plateau, averaging 5,000 feet in height, which runs along the entire length of the continent, and is buttressed on the west by a less continuous series of ranges. The *Sierra Madre* is the western buttress of the plateau in the south, where it forms the watershed, and near the point where it diverges from the Rocky Mountains the volcanic peaks of Orizaba (18,200 feet) and Popocatepetl (17,500 feet) rise as majestic summits, which, with Mounts St. Elias (18,100 feet), Logan (19,500 feet) and McKinley (about 20,000 feet), in Alaska, are the loftiest in North America. The plateau is also supported by the rugged snow-clad *Sierra Nevada*, which presents a very steep front to the west, cut into by rugged transverse valleys, with scenery of the wildest grandeur. Its highest peak is Mount Whitney (14,900 feet), and at Mount Shasta it passes into the *Cascade Range*, which runs northward, diminishing in height. Between latitudes 35° and 40° N. a lower mountain ridge, the *Coast Range*, joined to the Sierra Nevada on the north and the south, encloses a remarkable low plain, the Californian Valley, the rivers of which find access to the sea through an abrupt gap near the middle of the range. The eastern part of the centre of the plateau between the Rocky Mountains and the parallel Wahsatch Range, in longitude 112° W., forms the most elevated region, and is crossed by the Uintah Mountains, running from west to east. Cutting right through the Uintah range, and southward across the plateau to the Gulf of California, the great Colorado River and its tributaries lay bare the structure of the rocks (p. 275), showing the horizontal sedimentary strata, interspersed with outflows of basalt, based on a bed of Archæan gneiss. The other great river of the Pacific slope is the Columbia, the tributaries of which converge from all parts of the Rocky Mountains, from near Mount Brown in the north to the Wahsatch Range. In the north-west, where the low bordering ranges spread out, the great Yukon flows down the northern slope of the diminished plateau into Bering Sea.

The Great Basin.—Between the Wahsatch Mountains and the Sierra Nevada the plateau sinks slightly into a vast triangular area of internal drainage known as the Great Basin. It is most depressed near the sides, and rises in the middle in a series of mountain ridges. In the Quaternary period a wide sheet of water—called Lake Bonneville—occupied the eastern depression, and its shrunken remnant now forms the Great Salt Lake, at the base of the Wahsatch Mountains. A smaller expanse—Lake Lahontan—filled the western depression, which is now dotted by a series of little salt lakes under the eastern slope of the Sierra Nevada. The soil of the Great Basin is encrusted with borax and other alkaline salts deposited by the shrinking lakes. In recording their researches on this region, the officers of the United States Geological Survey have produced a series of the most fascinating memoirs on physical geography. The volumes on the exploration of the Colorado River by Major Powell, and on Lake Lahontan by Mr. Russell, are especially interesting.

The Appalachian Mountains, running parallel to the east coast, form a broad chain of moderate height, Mitchell's Peak, 6,700 feet above sea level, being the loftiest. They are true mountains of elevation, the alternate anticlines and synclines forming parallel ridges and longitudinal valleys, and their rocks are much more ancient than those of the western heights. In the south, Carboniferous strata and coal seams are laid bare in the transverse valleys, and the extension north of the St. Lawrence, in the broad low ridge of the Laurentides, is composed mainly of Archæan rock. The Appalachians, which include the Alleghanies, form a complete minor axis, giving the east of North America a short slope to the Atlantic and a long slope westward. The watershed follows the eastern ridge of the chain in the south, and the western ridge in the north; the Hudson River, however, cuts right across the entire chain.

Mississippi Basin.—One great valley, formed by the meeting of the long slopes of the two mountain axes, occupies the whole centre of North America. The southern and northern halves of this valley dip in opposite directions from a broad flat transverse ridge of very slight elevation in 48° N. The southern south-sloping half of the valley forms the basin of the Mississippi River. The Mississippi rises on the crest of the gentle transverse slope, and after a winding course of more that 1,000 miles receives on

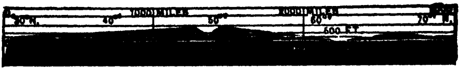

FIG. 61.—Section of North America on the meridian of 90° W. Vertical scale 300 times the horizontal. Sea-level marked O.

its right bank the Missouri, a river of much greater length, formed by the union of tributaries from 900 miles along the Rocky Mountain Range. Farther south the Arkansas, another long river, flows in from the Rocky Mountains. The steep eastern slope of this range, unlike that of the Andes, stops at an elevation of nearly 6,000 feet above the sea, and thence the rivers flowing to the Mississippi cross a slope so gentle that the land is spoken of as the Great Plains. As the elevation diminishes the slope decreases also, and the lowlands of the basin become known as the Prairies. The Ohio River, flowing down the slope of the Appalachians, is the largest tributary reaching the Mississippi on its left bank.

Arctic Basins.—In the northern half of North America several nearly level terraces, of from 200 to 300 miles in breadth, separated by narrow zones of steeply sloping land, descend from the Rocky Mountains toward Hudson Bay. The lower terraces are covered with boulder clay, and the terminal moraine of the great Pleistocene ice-sheet has been traced in the form of a huge ridge called the Grand Coteau des Prairies. This ridge turns the Missouri River to the south, and the Saskatchewan, flowing from near Mount Brown in the Rocky Mountains, to the north, thus separating the northern and southern slopes. Upon the lowest terrace, where the glacial remains are thickest, a line of wide shallow lakes stretches from 49° N. to the Arctic Sea. Lake Winnipeg in the south receives the Saskatchewan, and has an outlet by the Nelson River to Hudson Bay. This lake is the centre of a great but ill-defined drainage area, some of the hundreds of small lakes surrounding it being connected with several river systems, on account of the confused ridges left by the melting ice-sheet. Traces remain of a much larger ancient body of water, called Lake Agassiz, which included Lake Winnipeg, and many smaller lakes and river-valleys. The Athabasca, rising near Mount Brown, flows north-eastward to Lake Athabasca, which has an outlet northward to Great Slave Lake, whence the wide Mackenzie River flows parallel to the Rocky Mountains to the Arctic Sea, receiving the outflow from Great Bear Lake on the Arctic Circle.

St. Lawrence System.—The gentle transverse ridge separating the northern and southern slopes of North America is nowhere higher than 2,000 feet, and it only attains this elevation in the east. Its surface is slightly concave, the northern edge, called the *Height of Land*, being a continuation westward of the Archæan plateau of the Laurentides; while the southern edge, known as the *Great Divide*, is a prolongation toward the east of the moraine heaps of the Coteau des Prairies. The central hollow contains a remarkable group of lake basins, which are claimed, with some probability, to contain half of the fresh water in the world. Before the Ice Age they were probably in connection with the Mississippi river system, and ancient raised beaches surrounding them prove that they were evidently at one time much more extensive than now. The western group—Lakes Superior, Michigan, and Huron—are closely connected, and their surface stands about 600 feet above sea-level. From the south of Lake Huron they discharge into Lake Erie, whence the Niagara River leads northward into Lake Ontario, from which the broad St. Lawrence sweeps on to the Atlantic.

Australia is 2,300 miles in extreme length along the parallel of 26° S. (see section Fig. 62). The greatest breath is 2,000 miles along the meridian of 143° E. from Cape York in 11° S., which is the most

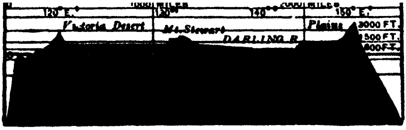

FIG. 62.—Section across Australia in 26° S. Vertical scale 300 times the horizontal. Sea-level marked O.

northerly point, to Cape Otway in 39° S. Incurves of the north and south coasts reduce the width to 1,100 miles in the narrowest part of the continent, while both the east and west coasts form bold outcurves. Tasmania rests on the continental shelf to the south, and New Guinea to the north. The average height of the land, as far as can be judged from the still incomplete surveys of the interior, is about 800 feet. In spite of this low elevation the proportion of land less than 600 feet above the sea is small, while the proportion between 600 feet and 1,500 feet in elevation appears to be greater than for any other continent.

Configuration of Australia.—The continent is apparently one low plateau, rising into a line of hills along the west coast, and ridged irregularly here and there by mountains in the imperfectly known interior. It sinks in the south-east to an extensive low plain (the Australian Basin) less than 600 feet above the sea. Half of Australia is made up of areas of internal drainage. The *Great Dividing Range*, forming the axis of the continent, rises along the eastern edge. It sweeps round the south-east coast under the name of the Australian Alps, and culminates in Mount Townsend or Kosciusko (7,300 feet). Thence it runs northward under different names as a chain of short ranges, scored by deep transverse valleys, sending short full rivers to the Pacific. Diminishing in height toward the north, it merges into the general elevation of the plateau. The ranges were, as a rule, ridged up out of primary rocks, the Silurian system being now most prominent in the south, and the Carboniferous, with thick seams of coal cropping out, farther north.

River Basins.—The southern part of the Dividing Range slopes down very steeply westward to the low plain of the Australian Basin. The Murray River flows westward across the Basin from its source near Mount Townsend, and after receiving the Lachlan and Darling it swerves to the south and enters the sea. Many long rivers are marked on maps converging from the east and north to the Australian Basin, but most of these are stony channels only occupied by water after rain, and many of the streams dry up as they flow. The Basin is divided by the Flinders Range west of the Murray, and its western part forms a depression scarcely raised above sea-level, in which lie Lake Torrens and Lake Eyre—salt lakes with no outlet. The whole depression is rimmed round with coral limestone of Tertiary age, and appears to have formed a wide shallow bay long after the rest of the continent was upheaved. The plateau to the west is a great desert not fully explored, and composed of the rock known as desert sandstone, fringed to the south by grand cliffs of tertiary limestone which line the Great Australian Bight as a wall about 400 feet high, unbroken by a single river for 1,000 miles.

Antarctica is the continent which lies within the Antarctic circle, only a few promontories, peninsulas or islands coming farther north than 67° S. The coast is so encumbered by sea-ice and so heavily masked in parts by the seaward extension of a great ice-cap that only a small portion of it has yet been explored. We know, however, that a great continent and not merely a group of islands surrounds the South Pole, for the sediments dredged from all parts of the Southern Ocean abound in fragments, and sometimes yield great blocks of true continental rocks which have been carried out to sea by the icebergs. The expedition of Sir James Ross in the first half of the nineteenth century, and those of Borchgrevink, Scott, Shackleton, Amundsen, Mawson in the twentieth century, have shown the existence of a great mountain range running along the coast of Victoria Land from near Cape North in 71° S. to at least 88° S., buttressing a vast snow-covered plateau of unknown extent, rising to more than 10,000 feet at the South Pole. The other margins of the continent, portions of which or off-lying islands have been discovered by various explorers since the time of Bellingshausen in 1820, are still too little known to allow of any comparison with the continents which radiate from the North Pole. It is known, however, that the great mountain ranges consist largely of up-ridged sedimentary rocks, and that volcanic activity manifests itself in the great peak of Mount Erebus and in other places. The highest summits in Victoria Land include Mount Markham 15,000 feet in latitude 83° S., and Mount Kirkpatrick 14,600 feet in 84° 20′ S. Between the mountains of this range the most stupendous glaciers in the world make their way toward the coast, though many of them are apparently receding and their tips no longer reach the sea.

Africa presents a typical triangular outline resembling that of South America, but the north-western outcurve is much more pronounced, while the north-eastern outcurve is broken by the depression of the Red Sea. Round Africa the Continental Shelf is extremely narrow, and the islands it bears are few and small, while the coast-line is less indented than that of any other continent. The greatest length, nearly 5,000 miles, lies along the central meridian of 20° E., and the greatest breadth, 4,500 miles, is on the parallel of 10° N. Africa is the only continent crossed by both tropics, the equator passing nearly through the centre. The average elevation of Africa is nearly that of all the land; but no other continent has such a small proportion of land below 600 feet in height (one-eighth of its area), and none has so great an extent (nearly two-thirds) between the heights of 600 and 3,000 feet.

Slopes of Africa.—A section drawn across the continent, along the equator (Fig. 63), hardly shows how completely the typical continental structure is departed from, as Mount Kenia is only an isolated mass, not part of a range. All the rivers pursue singularly curved courses, unlike those of any other continent, and where they drop over the edges of the plateaux form great cataracts. The watersheds are not dominated by mountain ranges, but by the broad backs of plateaux, out of which the main features of the land-slopes have been carved by erosion. The Atlas mountains, a true folded mountain range, near the coast in the north-west, rise into a succession of snow-crowned peaks, the loftiest of which probably reach heights exceeding fifteen thousand feet above the sea. All round the coast, except in the north and north-west, the edges of the plateau present a mountainous aspect, and several great volcanic summits rise from their highest levels. Kenia, Kilima-njaro, and Ruwenzori reach heights approaching 19,000 feet above the sea. The loftiest elevated belt, which may be termed the *Great Plateau*, runs from the Red Sea southward and westward across the continent, and may be looked on as forming the main axis. Its greatest elevation is in the rugged valley-riven plateau of Abyssinia, and it continues highest on its eastern side. A belt of eastward-sloping land, down which the *Zambesi* pursues a cataract-broken course to the Indian Ocean, separates the Great Plateau from a smaller plateau which fills the southern extremity of the continent. This Southern Plateau sinks to the sea in steep terraces bordered on the south and east by curved mountain ranges, the most important of which is the Drakenberg. It dips to the west and is drained by the

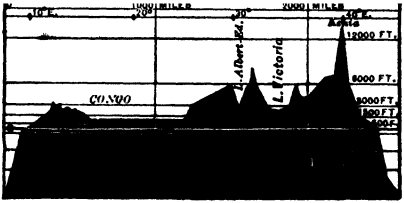

FIG. 63.—Section across Africa on the equator. Vertical scale 300 times the horizontal. Sea-level marked O.

Orange River, a rapid stream flowing through a deep cañon far below the general level. The Great Plateau sends off three long branches of high land toward the north-west, which cannot be clearly traced on a map unless the contour-line of 1,500 feet is shown. The first or Coast Ridge runs round the west coast and descends to sea-level in terraced mountain slopes. It bears the high Cameroon Mountains near the angle of the Gulf of Guinea, and slopes down very gradually inland. Its western extension is pierced by the great River Niger, flowing into the Gulf of Guinea. The second or Central Ridge runs from the equator toward the Atlas Range across the northern high plain. Uniting with the Coast Ridge in latitude 5° N. and again in 20° N. it bounds two great basins, of which the southern or equatorial is, on the average, higher, and the northern lower, than 1,000 feet. The third or Red Sea Ridge runs along the Red Sea coast from the northern extremity of the Great Plateau. Two remarkable Rift Valleys, outlined by faults, furrow the Great Plateau. The eastern is a continuation of the Dead Sea and Red Sea depression and contains Lake Rudolf; the western contains Lakes Albert, Albert Edward, and Tanganyika. Both Rift Valleys seems to converge in the hollow containing Lake Nyasa. They extend from north to south for a distance of more than 2,000 miles.

Nile River System.—Lake Albert collects the head-waters of the Nile, receiving the Semliki River from Lake Albert Edward lying at the base of Ruwenzori, and fed by the ceaseless torrents from that mountain. It also receives at the northern extremity the outflow of the largest lake in Africa, the Victoria Nyanza, which is situated on a higher part of the plateau at an elevation of 3,300 feet, between the two Rift valleys. This branch, the Victoria Nile, is broken by a succession of falls as it descends the steep edge of the plateau. From Lake Albert the White Nile flows northward to the Mediterranean across the desert which stretches between the slopes of the Red

Sea Ridge and the Central Ridge, receiving many tributaries from both. The rainy heights of Abyssinia send down the Blue Nile and the Atbara, on which the periodical flooding of the Nile depends, but after the junction of the latter stream the Nile flows in three great bends across the parched low plain to its delta without receiving another drop of water, and subject to continual evaporation. The six famous cataracts which occur in its lower course are produced by its bed crossing bars of hard rock, and they thus differ in their nature from the cataracts of the plateau rivers of the south.

Congo Basin.—Shut in between the Central and West Coast Ridges, the equatorial basin was probably at one time a great inland sea several times larger than the Caspian. Its waters found an outlet across a comparatively low part of the West Coast Ridge, which they eroded into a deep gorge and so drained the lake into the Atlantic, leaving a basin of fertile soil. Rivers flow into the circular basin from the high ground on every side and become tributaries to the giant Congo. This river descends from the Great Plateau at the equator, foaming over the cataracts of Stanley Falls, sweeps through the basin in a magnificent curve as a navigable stream for 1,000 miles, and bursts in a grander chain of cataracts over the plateau edge through the gorge of Yellala. The source of the Congo lies in the Great Plateau, about 13° S., Lake Bangweolo, 4,000 feet above the sea, serving as a reservoir to collect the head-waters. In its northward course the river is joined by the Lukuga from Lake Tanganyika in the eastern Rift Valley, 2,600 feet above the sea; but it is only when the level of that lake is raised considerably above its average height that it overflows. Tanganyika, like most continental lakes, was once much larger, and appears to be shrinking into a basin of internal drainage, destined ultimately to become a salt lake.

Chad Basin and Sahara.—The northern basin enclosed by the West Coast and Central Ridges, so far as it has been explored, appears to have no outlet. Lake Chad, a sheet of shallow water varying in size from 4,000 to 10,000 square miles, and 800 feet above the sea, receives the Shari and other rivers from the south, and overflows in the rainy season to a lower enclosed basin in the north-west, where the water is evaporated. The Niger forms a great semicircular bend north of the Gulf of Guinea and east of Lake Chad; it has fewer cataracts than any other great river in Africa, and traverses a diversified and well-watered country. To the north, nearly the whole breadth of Africa forms the sandy internal drainage area of the Sahara. The Sahara is on the whole an elevated region, although it dips in the west and north to a low plain with some small depressions, called *shotts*, below sea-level.

Eurasia, containing one-third of the land of the globe and occupying the central part of the Eastern World Ridge, when looked at largely, shows the typical features of a triangular outline and a mountainous axis separating a long from a short land slope, and supporting a plateau of internal drainage. It is the least tropical of the continents, only the three south-eastern peninsulas crossing the tropic of Cancer. The greatest length of Eurasia is about 7,000 miles, from Cape Roca in 9° W. to East Cape on Bering Sea in 170° W., the continent extending more than halfway round the Earth. The greatest breadth is about 5,000 miles, along the meridian of 105° E., from Cape Chelyuskin in 77½° N. to Cape Buru in 1¼° N. at the extremity of the Malay Peninsula. More than one-quarter of this vast area slopes together, forming basins of internal drainage, and almost a quarter slopes north toward the Arctic Sea, giving a peculiarly inaccessible character to half the continent and tending to increase the severity of its continental climate. The low plain of Eurasia forms a great triangle with its base along the Arctic Sea. This is divided into a smaller western and a larger eastern portion by the low belt of the Ural Mountains in 60°

E., which may be taken as forming the boundary between Europe and Asia. A section of the continent, along the meridian of 90° E. (Fig. 64), gives a general idea of the structure. In its main features the west coast of Europe corresponds on a smaller scale with the east coast of Asia—the Scandinavian peninsula answering to Kamchatka, the Baltic to the Sea of Okhotsk, the British Islands and North Sea to the Islands and Sea of Japan. Similar resemblances connect the south coast. Spain and Arabia are both square and massive plateaux; Italy and India are both separated from the continent by a low plain under a lofty mountain wall, and taper southward, ending in a large island; and the Balkan peninsula, like Indo-China, is mountainous, deeply indented, and terminates in an archipelago.

Asia, the highest as well as the largest of the continents, has an average elevation of more than 3,000 feet. The zone of heights between 600 and 1,500 feet is narrower that in any other continent, and more than one-sixth of the surface stands higher than 6,000 feet above the sea. The orographical centre of Eurasia is formed by the region of the *Pamirs* (in 38° N. and 73° E.), as large as Ireland, and rising to 25,800 feet above the sea in its highest summit, while its lowest point is 9,000 feet; it is called by the dwellers in the region "The Roof of the World." From this centre, mountain chains spread out like the ribs of a fan to the east and to the west. The lofty range of the *Hindu Kush*—cleft by a few very high passes and rising into summits 24,000 feet high—runs south-west from the Pamir, separating the low plain of India from the low plain of Northern Asia. It branches in lower ridges to the south and west, enclosing the internal drainage area of Iran (Persia), which lies at an average height of 3,000 feet. The northern mountain ridge, sweeping round the south shore of the Caspian as the Elburz Range, merges into the broken Plateau of Asia Minor. Here the southern ranges also converge, walling off the Plateau of Iran from the low plain of Iraq, with the Tigris and Euphrates flowing to the Persian Gulf. Mount Ararat, 17,000 feet above the sea, is the grandest summit in Asia Minor. The plateau spreading southward occupies Arabia, most of which is an internal drainage area. One of the most perfect types of a folded mountain chain is presented by the *Caucasus*, which runs from the Black Sea to the Caspian as a magnificent barrier between the heights and valleys of Asia Minor and the low, level plain of Europe, and culminates in Mount Elbruz, 18,500 feet high. In the calculation of elevation in the tables on p. 302 this chain is assigned to Europe.

Eastern Asiatic Mountain System.—The mountain chains which radiate eastward from the Pamirs converge at two centres, one near the north of the Indo-China peninsula, the other near the Sea of Okhotsk. Between these three knotting points the long mountain ranges seem on the map to droop in graceful folds. They define an area which is as large as South America, and is occupied by the highest and most extensive plateaux in the world. The southern front of the whole system is the triple chain of the *Himalaya*, sweeping in a noble curve south-eastward from the Pamirs, rising from the plain in stately slopes and ridges, and crowned by innumerable snowy summits, amongst them Mount

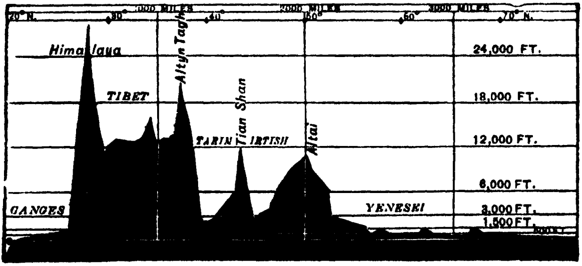

FIG. 64.—Section across Asia on the meridian of 90° E. Vertical scale 300 times the horizontal. Sea-level marked O.

Everest (29,000 feet), the culminating point of the Earth's surface. It is cleft by no passes less than 15,000 feet above the sea. The *Karakorum*, a short but very lofty range (its chief summit, Dapsang, is 28,700 feet above the sea), runs parallel to the Himalaya from the Pamirs. Thence also the long and lofty range known as the *Kuen Lun* stretches east, and sends off the Altyn Tagh and Nan-shan range in a north-easterly curve. Between the Himalaya and the Kuen Lun extends the high plateau of Tibet, 13,000 feet above the sea, and measuring 2,000 miles from east to west, and 1,700 miles from south to north. The plateau slopes downward to the east, and the mountains and valleys which ridge its surface converge into a series of close parallel ranges at the Indo-China knotting point. Thence some ranges diverge southward into the peninsula, some descend eastward toward the plain, and some sweep north-eastward to the Okhotsk knotting point as the Khingan Chain. Most of the Tibet high plateau is free from snow in summer owing to the extreme dryness of the air, and is a region of internal drainage. The great rivers Indus and Brahmaputra rise in the most northerly longitudinal valley of the Himalaya, and break a way round the northern and southern extremities of the range to the southern plain. Other rivers, amongst them the Irawadi and the Mekong, flow south in the longitudinal valleys of the Indo-China peninsula. Rising on the eastern margin of the plateau, the Yellow River (*Hwang Ho*) sweeps north-eastward until it breaks a passage through the Khingan Range and turns south again over the eastern plain. The Yang-tse-Kiang rises close to the Yellow River; at first it rushes southward through one of the longitudinal valleys, but making a gap through the bordering mountain, and piercing in turn several parallel chains, it swerves northward and emerges from its gorges on the plain, to approach the Yellow River once more near its mouth.

Tarim and Gobi Basins.—Standing with one foot, as it were, on the northern edge of the Tibet High Plateau, the Kuen Lun and Altyn Tagh reach down with the other to the much lower High Plain of the Tarim River and the Gobi Desert, which averages a little more than 3,000 feet above the sea. The vast range of the *Tian Shan* ("The Mountains of Heaven"), with some summits 24,000 feet above the sea, stretches north-eastward from the Pamirs, and walls in the northern side of the Tarim basin. Many rivers from the slopes of the amphitheatre, formed by the converging mountains, unite in the Tarim, which flows east for 1,300 miles to dry up in the swampy salt lake of Lob Nor. The Tian Shan is continued north-eastward by a number of ranges, including the Altai, the Sajan, and the plateaus of Vitim and Aldan, all of which rise much higher than the Gobi, and are separated from each other by mighty valleys sloping into the northern low plain. They are united by the Yablonoi and Stanovoi Ranges to the great Khingan Chain at the Okhotsk knotting point, and continue in the diminishing Stanovoi Range to East Cape. There is evidence that the Gobi High Plain, now covered in most parts with drifting sand, was once a vast inland sea, discharging its surplus waters by the great valleys between the northern heights into the Arctic Sea. Now the few rivers which flow into it from the surrounding mountains end in the sand or in small salt lakes. Near Turfan there is even a dry depression below sea-level. Rising on the western slope of the Khingan with tributaries from the eastern slope of the Yablonoi, the great Amur River cuts through the Khingan Chain and several parallel ranges, and finds its way into the Pacific.

Northern Low Plain.—The Tian Shan and other northern mountains descend in terraces to a narrow belt of undulating land about 1,000 feet in elevation, which sinks into the wide low plain less than 600 feet above the sea. Lake Balkash, without outlet and intensely salt, occupies a depression north of the

Tian Shan, from which it receives several rivers, but its area is steadily diminishing by evaporation. Lake Baikal, to the north-east at a higher level, receives much water from the Altai and surrounding heights, but its outflow is comparatively trifling. The northern plain bears evidence in its gravel beds of having emerged from the sea in the Quaternary period, and the gradual desiccation of Asia may date from the time when its upheaval cut off from the interior the tempering influence of the sea. Three vast rivers, only matched for length of course and area of basin by the giant streams of Africa and America, flow from the mountains across the plain to the Arctic Sea during the few months when they remain unfrozen. The Lena, farthest east, rising near Lake Baikal, terminates in a wide delta. The Yenisei flows due north from the Sajan Mountains, and receives no considerable tributaries on its left bank, but the Angara, from Lake Baikal, and the two Tunguskas flowing from the east, enter on its right bank. The Ob and Irtish flowing north from the Altai unite, and after receiving tributaries from the eastern slope of the Urals, enter the head of a long narrow gulf of the Arctic Sea. From the Pamir the Amu Daria and Syr Daria (Oxus and Jaxartes) flow across the desert low plain, rapidly dwindling by evaporation, to Lake Aral, the area of which is shrinking. In the time of the early Greek geographers the Oxus swerved to the west and entered the Caspian, and its old bed, from which it seems to have been diverted by sand-dunes, may still be traced. At a more remote period the Aral Lake was part of a large sea which covered the Caspian basin and communicated with the Mediterranean, and in Quaternary times spread over the low watershed of the Ob to the Arctic Sea.

Indian Peninsula. — A great low plain extends along the base of the Himalaya, separated by a gentle ridge into a south-western slope traversed by the Indus on its way to the Arabian Sea, and a gentler eastern slope, along which the Ganges flows to the vast delta which it shares with the Brahmaputra. An ancient and much denuded plateau largely built up of volcanic rocks fills the southern part of the peninsula. This plateau is loftiest on its western edge, where it sinks in abrupt terraces to the sea, presenting a mountain-like wall known as the Western Ghats. The more gentle slope to the east has been cut by numerous rivers into wide valleys, and the broken plateau edge forms a lower and less regular line of heights more remote from the sea, called the Eastern Ghats. The coast-line on both sides is remarkable for its unbroken character and the gentle shelving of the beach.

Europe.—A bunch of peninsulas thrust out into the Atlantic Ocean, and from its well-marked sea-climate, may be appropriately termed the Temperate Continent. An axis of true mountains of elevation runs through Southern Europe, and another forms the low belt of the *Urals* on the boundary with Asia. A rim of ancient plateaux worn into mountains of denudation marks the north-western border in Scotland and Scandinavia. Within this elevated frame the land is a wonderfully uniform low plain, fully half of the continent being less than 600 feet above the sea. Only one-sixth of the surface has an elevation greater than 1,500 feet. The lines of elevation have a comparatively slight share in determining the slopes, which exhibit none of the typical continental simplicity.

Southern Mountain System. — The *Alps*, the most thoroughly studied mountain system in the world, form the orographical centre of Europe. The main chain runs east and west in a series of ridges separated by longitudinal valleys and cleft by transverse valleys into distinct mountain blocks. Mont Blanc (15,800 feet) is the loftiest summit. On the south the main range slopes down steeply to the low plain of Lombardy, which is enclosed to the south by the *Apennines*, which unite with the western Alps. The northern range of the Alps descends to a plateau sloping gently to the north and east, and buttressed by the limestone ridges of the *Jura.* To the east the system runs southward into the Balkan peninsula as the Dinaric Alps, also a limestone chain, full of the characteristic scenery wrought by erosion and subterranean solution (p. 265). The *Balkan Range* stretches east and west across the peninsula, sloping down to the low plain of the Danube in the north. The granite heights of the *Black Forest* Mountains run north of the Jura, and are continued by a broad ridge of Palæozoic rock, which dips down into the northern plain in an outcrop of the coal-measures. A broken hill country extends north-eastward from the Alpine plateau, sinking in elevation toward the north, and terminating in the Harz Plateau in 52° N. The hilly region rises in the east into the steep heights of the *Bohemian Forest,* which runs north-west from the eastern extremity of the Alps. The Bohemian Forest Range turns sharply north-eastward as the *Erzgebirge* or Ore Mountains, the rocks of which are traversed by veins of many metallic ores, and these in turn run eastward as the *Sudetic Range.* Supported between the three ranges the irregular plateau of Bohemia rises toward the south, and is terminated by the higher land of Moravia. Eastward the Sudetic Range adjoins the fine curve of the *Carpathian Mountains,* which sweep steeply round the low Hungarian Plain, and sink down gradually to north and east into the great Northern Plain. The Carpathian Range terminates in the *Transylvanian Alps,* which first run parallel to the Balkans, and then converge in the west until they almost meet that range. West of the Alps the Vosges Mountains run northward, separated by a wide flat valley from the parallel range of the Black Forest, and terminating in the same belt of ancient rock. Separated by the narrow valley of the Rhone on the west, the Auvergne plateau, studded with extinct volcanic cones, rises in a steep terraced slope known as the Cevennes Mountains, and sinks more gently to the low plain on the north and west. The rugged high plain of the Iberian Peninsula is shut off from Northern Europe by the straight line of the *Pyrenees*, one of the steepest mountain ranges, and presenting some of the finest examples of erosion in the form of cirques or round-headed valleys.

Rivers of Western Europe.—In Western Europe the main watershed (see Plate XIII.) lies, as a rule, nearer the south coast than the north, following roughly the Pyrenees, the Cevennes, the Vosges, the Alps, the Black Forest, the Franconian Jura, the Moravian Plateau, and the Northern Carpathians. Thus the northern slope is long and the southern slope short. In Eastern Europe the watershed is nearer the north coast, crossing the low plain on a ridge of very slight elevation, which stretches from the Carpathians north-eastward to the Urals, and swells up into the Valdai Hills about the centre. This gives a comparatively short slope to the north and a long slope to the south. The rivers of Western Europe, the Guadiana, Tagus, and Douro in the Iberian Peninsula, and the Garonne, Loire, and Seine from the Auvergne high plain, flow to the Atlantic Ocean directly. The rivers of Central Europe all originate in the Alps and their connected ranges. The Rhone and Rhine flow in opposite directions along the great longitudinal valley which bisects the Alps. The Rhone, descending from its source in the great central mass of the St. Gothard, enters the Lake of Geneva, escapes westward through the Alps, and sweeps south to the Mediterranean, beneath the steep front of the Cevennes. Flowing east, the Rhine turns northward into Lake Constance, passes out westward between the Jura and the Black Forest, turns north through the wide valley between the Black Forest and the Vosges, crosses the ancient rock plateau by a series of grand gorges, and, flowing over the low plain, oozes into the North Sea along several branches embanked above the sunk plain of Holland. The Elbe drains the Bohemian plateau, and breaking through the mountain barrier in "the Saxon Switzerland," between the Erzgebirge and the Sudetic Range, winds across the low plain northwestward to the North Sea. The Oder and Vistula, from the northern slopes of the Sudetic Range and Carpathians, flow northward to the Baltic. The Danube is remarkable for its disregard of mountain barriers. It rises on the eastern slope of the Black Forest, flows eastward across the plateau north of the Alps, and finds a way between the Alps and the Bohemian Forest Range. After penetrating some smaller ranges it turns south in several parallel channels across the flat plain of Hungary, which was probably once a great lake. It is joined by the Inn, the Drave, and Save from the Alps, and the Theiss from the Carpathians, as it crosses the nearly level plain. The narrow channel of the Iron Gate, between the opposed ranges of the Carpathians and Balkans, allows the Danube to enter the open plain, across which it flows to a delta on the Black Sea.

Rivers of Eastern Europe.—The long southern slope of Eastern Europe is traversed by the great rivers Dnieper and Don, flowing through gorges cut in the low plain to the Black Sea. The still greater Volga, rising in the Valdai Hills, winds eastward and southward, always encroaching on its right bank, which is high and steep, and always leaving successive alluvial terraces on its low left bank. The Oka is the most important of its many tributaries on the right, and on the left the Kama, flowing from the Ural Mountains, is the largest. When the Volga reaches sea-level its course is directed south-westward, parallel to that of the Don and very near that river, but the great stream turns sharply south-eastward, splitting into numerous channels, and finally enters the closed Caspian Sea by a great delta. The short northern slope of Eastern Europe is occupied by the basins of the Pechora flowing to the Arctic Sea, and the Northern Dwina to the White Sea.

Lake District of Northern Europe.—North of the Baltic the long slope of the peninsular mass of land, including Scandinavia and Finland, is toward the south. The great Lake Ladoga, which discharges its overflow by the short swift Neva into the Baltic, receives the drainage of a vast lake district—Lake Onega on the north, Lake Ilmen on the south, Lake Saima and innumerable connected lakelets on the west, all draining to it. At Imatra, on the river joining Lakes Saima and Ladoga, the most impressive cataract in Europe is formed in a nearly flat country by the water pouring through a narrow and steep bed of granite, which converts the course for more than a mile into a thunderous mass of feathery foam and leaping yellow waves. All the lake-basins of this district are due to glacial action, and date from the same period as those of North America. They are, as a rule, shallow, some having been scooped out of a flat floor of crystalline rock, while others are formed by the irregular accumulation of glacial detritus. About one-sixtieth of the area of Europe is covered with lakes, but in Finland the proportion is one-tenth.

The British Islands.—An upheaval of 300 feet would convert the bed of the North Sea, south of a line drawn from St. Abb's Head to the Skaw, into a low plain continuous with that of England and of Northern Europe. During the evolution of Europe elevation and subsidence have repeatedly raised the whole region into land and again lowered it under water. Viewed as a whole, the island of Great Britain is higher toward the west than the east (see Plate XVI.). The watershed lies near the west coast, giving a long eastward slope traversed by the longest rivers, yet if we exclude Ireland the area of land draining to the North Sea is exactly equal to that draining to the English Channel and the Atlantic. The east coast is comparatively smooth, with occasional wide funnel-like estuaries and scarcely any islands while the west coast is very deeply indented by winding fiords or sea-lochs, and many groups of large and often lofty islands. No true mountain ranges can now be traced in the British Islands, the forms of the high land being the result of denudation. Glacial markings have been found over all the British Islands except the extreme south of England, and the existing configuration has thus been modified in most places. Mountains, below the height of 3,000 feet at least, have acquired a more or less flowing outline through glacial grinding; and the low land has been largely enveloped in boulder clay and similar accumulations.

Scotland.—On the map of vertical relief (Plate XVII.) the northern part of Great Britain is seen to be divided into three natural regions stretching across the island from north-east to south-west. Most of the area north-west of a line drawn from the Firth of Clyde to near Aberdeen is occupied by the Highlands. This is an old plateau, largely composed of crystalline schistose rocks, and pierced by many granite-like masses. The heights, separated by deep valleys, are rugged and often precipitous, crowned by crests of splintered rock. The Highlands are divided into a northern and a southern group by the Great Glen which unites the Moray Firth with the Firth of Lorne, and contains Loch Ness and Loch Lochy, two long, narrow, fresh-water lakes. The highest point of Great Britain is the mass of Ben Nevis (4,400 feet), near the south-western extremity of the Great Glen, but a greater area of scarcely lower elevation occurs round Ben Macdhui. South of the Highlands stretches a broad low plain—the Midland Valley—diversified by lines of hills like the Pentlands, Ochils, and Sidlaws, and isolated precipitous crags such as those occupied by the castles of Dumbarton, Stirling and Edinburgh. These abrupt heights are due to masses of hard volcanic rocks formed in the Carboniferous period or later, and now exposed by the more rapid erosion of the softer strata which had buried them. *Along the border of the Highlands there is a* strip of Old Red Sandstone sharply separated from the crystalline schists, slates, etc., by the Great Fault which runs from the Firth of Clyde to near Aberdeen. Along the southern edge of the plain a similar strip of the same formation is terminated by a line of faults stretching from near Ayr to near Dunbar. Carboniferous strata—with the coal-measures cropping out in several places—occupy the centre of the Lowland Valley. The Southern Uplands, which form the third division, are a group of rounded grassy and often peat-topped hills, lower than the Highlands, divided from each other by gently sloping valleys, and composed mainly of Silurian rocks, although the Cheviot Hills on the southern boundary are largely of igneous origin.

England and Wales.—The mountainous Lake District of north-western England has been carved by erosion from great masses of Silurian rock, but numerous outbursts of ancient volcanic material have given ruggedness and grandeur to many of the summits. The mountains of North Wales culminating in Snowdon (3,570 feet) generally resemble those of the Lake District in their geological structure. They slope in steep terraces to the sea on the west, and dip down more gently to the low plain of England on the east. In South Wales the mountains of circumdenudation are lower, and the Silurian rocks give place to Old Red Sandstone. This is in turn covered by a great expanse of Carboniferous rocks in the south, where the coal-measures come to the surface. Ancient Primary rocks, especially lower Carboniferous and Devonian strata, build up the peninsula of Devon and Cornwall, but great intrusions of igneous rock form the hard framework which the sea has wrought into a coast-line vying in grandeur with that of the north-west of Scotland. The band of high land in the north of England known as the Pennine Chain slopes to the sea on the east, adjoins the Lake District on the west, and to the south-west and south gradually spreads out and sinks into the low plain. The hills and dales of this region are carved out of a great anticline of Carboniferous rocks, comprising limestones, coal-measures, and grits or coarse sandstones. The crest of the anticline has been denuded down to the grits, while the coal-measures and limestones crop out on the slopes, forming extensive coal-fields. Most of England to east and south is occupied by a low plain built up of Secondary and Tertiary rocks, each sheet of rock dipping under a newer stratum towards the south and east. The elevation of this part of the country rarely exceeds 600 feet, but it is diversified by many hills formed by the edges of successive strata. From the plain the rugged heights of Primary rocks in the west and north rise as from a sea, the whole character of their scenery contrasting with its gentle ridges and low undulations. An irregular line of heights forming a steep escarpment to the west and a gentle slope to the south-east overlooks the Severn Valley as the Cotteswold Hills. It is continued north-eastward to the Humber, and thence on the other side of the estuary northward, where it swells up into the Yorkshire Moors, and terminates in a line of cliffs along the coast. This edge is the outcrop of a great sheet of relatively hard oolitic limestone (Jurassic period) which dips gently to the south-east under the chalk and is separated in the north and west by a lower strip of older but less durable Secondary rocks from the Primary system. A similar but more broken escarpment is formed farther south by the outcrop of Cretaceous rocks, which also dip gently to the south-east. This Chalk ridge, reaching its greatest height in Salisbury Plain, the Marlborough Downs, and the Chiltern Hills, is continued in the lower East Anglian heights running north-eastward into Norfolk. It reappears north of the Wash as the Wolds of Norfolk, and north of the Humber as the Yorkshire Wolds, terminating in Flamborough Head. From Salisbury Plain two low chalk ridges diverge: one runs eastward as the North Downs, the other south-eastward as the South Downs, and both end in the Chalk Cliffs of Kent. Both the North and South Downs show steep faces to the low Wealden plain, which surround the older sandstone of the Forest Ridges. The River Thames, rising on the southern slope of the Oolitic ridge, flows through the Chalk ridge between the Marlborough Downs and Chiltern Hills, and turns eastward to its shallow estuary on the North Sea across a plain of Tertiary rocks, consisting of clay, sands, and marls of Eocene age.

Ireland.—The east coast of Ireland is comparatively low and unindented, while the west coast is cut into many long inlets lined by lofty cliffs and fringed with islands. The configuration of Ireland is entirely different from that of Britain. A low plain occupies the whole interior, and its elevation is so slight that a subsidence of 250 feet would unite the Irish Sea and the Atlantic across the island. Isolated groups of lofty mountains rise at irregular intervals round the outer edge, the highest being Carn Tual (3,400 feet) in the south-west. The Shannon, the largest river, flows southward along the centre of the plain, and turns westward into the Atlantic. Geologically the low plain of Ireland is composed of a vast expanse of the Carboniferous formation, in which the coal-measures are only slightly developed. The mountains are islands of more ancient rock, Silurian and Old Red Sandstone, with metamorphic schist and gneiss, like those of the Highlands in the north-west. Great masses of volcanic rock occur in the north-east, where the basaltic columns of the Giant's Causeway form some of the most remarkable scenery of Europe. These harder rocks are prominent on account of their resistance to the erosion which planed down the soft strata into a uniform surface. The centre of Ireland is full of shallow lakes and vast peat-bogs, formed by the decay of vegetation in the wet climate on ground too flat to allow of natural drainage.

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CHAPTER XVII

LIFE AND LIVING CREATURES

The World without Life.—The World as a whole may be compared to a great house. Geology describes its materials, records the process of building, and keeps account of the alterations which are always being carried out. Oceanography has to do with the currents of water interchanged between the tropical boilers fired by the central furnace of the Sun and the polar refrigerators. It explains the arrangements by which those rooms most exposed to the furnace are cooled down by iced water, whilst those more remote have their temperature raised by copious warm streams. Geology records many past contests between the furnace and ice-house in controlling the heating arrangements, and many changes in the direction of the hot and cold water-pipes. Meteorology discusses the still more complicated and variable methods of ventilation in the various rooms, influenced as they are by the circulation of water and by the structure of the buildings. Astronomy has something to say as to the arrangements for lighting the great house, explaining how each room is illuminated with a certain brilliancy for a particular time. Astronomy also supplies reasons for the changes in the strength of furnace and refrigerators in the past. Geography concerns itself with a plan of the house so far as it is completed, showing the dominant style of architecture and tracing the modifications adopted in the several parts, and gives a general view of all the arrangements.

Life in the World.—Geology and Oceanography bear evidence of changes in structure which have not yet been fully explained by the laws of matter and energy. These laws enable us to understand that water should in certain conditions dissolve carbonate of lime and silica. But they cannot account as yet for the opposite process which is at work in exactly the same physical conditions. Carbonate of lime and silica separate out from solution and assume the solid form, not with the uniform sharp angles and smooth faces of crystals, but with curved and varied outlines decorated with delicately-etched designs of infinite variety. Fossils are evidently due to a similar temporary reversal of ordinary chemical and physical change. These reversed processes are recognised as the characteristic result of life. Geology may be said to present to us a view of the world as a vast cemetery full of monuments of past generations of living creatures. When we look around us in the open country our eye is not, as a rule, attracted by bare rocks or soil, but by a covering of grass, flowers, and trees, amongst which beasts and birds and insects are moving. These are the living inhabitants of the great World House. Between them and the rooms they inhabit there is a close and ever-varying relation, the comprehension and description of which is the central aim of Physiography.

Classification of Living Creatures.—Everyone can tell at a glance that a bush and a cow belong to widely different classes; indeed, a close observer might fail to find anything in common between them. It is easy and natural to class trees, bushes, herbs, grass, and even seaweeds, as essentially similar, and to recognise them all as *Plants*. Similarly, although four-footed beasts, birds, reptiles, insects, and fishes differ a good deal amongst themselves, they are classed together, almost without a thought, as *Animals*. A great gulf seems to separate the Vegetable and Animal kingdoms, to use the names given by Linnæus, who laid the foundations of the modern classification of living things. Plants are rooted in the soil; animals are free to move over the land, through the water or air. When carefully studied, both the great kingdoms are found to fall into a number of natural groups, the members of which show a regular advance in the complexity of structure. Between the simplest groups of each kingdom it is difficult and often impossible to trace any difference, for both the simplest plants and the simplest animals are formed of a single transparent cell, and are equally capable of spontaneous movement. All living creatures are termed organisms, and the science which takes account of them with special regard to their common characteristics is termed *Biology* (literally Life-lore). The classification and life-history of plants are the objects of the department of Biology known as *Botany*, while the department known as *Zoology* is similarly occupied with the study of animals.

Classes of Plants.—Botanists group plants into sub-kingdoms, classes, natural orders, genera, and species. A *species* includes all the individual plants which are so much alike as to make it certain that they are descended from the same stock and which are mutually fertile. A *genus* includes a group of species closely related to each other. A group of related genera forms a *family*, a number of allied families forms an *order*, and the orders are themselves grouped in *classes*. Thus, for example, in the class of Dicotyledons there is an order called Ranunculaceæ, which includes several families and many genera, amongst others that of Ranunculus, which in turn includes many distinct species. Following the suggestion of Linnæus, each species—that is, each separate kind of plant—is known to botanists by the name of its genus, followed by a specific name. One particular kind of buttercup is thus termed

Ranunculus acris. The classes of plants, with a typical example of each, are as follows:—

I. THALLOPHYTES.
  PROTOPHYTA—Bacteria.
  ZYGOSPOREÆ—Diatoms.
  OOSPOREÆ—Fucus.
  CARPOSPOREÆ—Most Seaweeds and Fungi.

II. MUSCINEÆ.
  HEPATICÆ—Liverworts.
  MUSCI—Mosses.

III. VASCULAR CRYPTOGAMS.
  EQUISETINEÆ—Horsetails.
  FILICINEÆ—Ferns.
  LYCOPODINEÆ—Club-mosses.

IV. PHANEROGAMS (*flowering plants*).
  GYMNOSPERMS—Pines and Firs.
  MONOCOTYLEDONS—Lilies.
  DICOTYLEDONS—Buttercups.

Classes of Animals.—Animals are more numerous and varied in their kinds than plants, and their classification, according to resemblances and differences, is in consequence more complex. Species, genera, families, and orders are distinguished much in the same way as with plants, and animals also are named after both genus and species. The great groups into which they are divided (and the classes of the last group), with typical examples, are as follows:—

PROTOZOA—Radiolarian, Foraminifera, Amœba, etc.
PORIFERA—Sponge.
CŒLENTERATA—Jellyfish, Sea-anemone, Coral.
ECHINODERMATA—Starfish, Crinoid, Sea-urchin.
VERMES—Worms.
ARTHROPODA—Lobster, Barnacle, Millipede, Spider, Insects.
MOLLUSCA—Oyster, Snail, Pteropod, Cuttlefish.
PRIMITIVE VERTEBRATES—Tunicate, Lancelet.
VERTEBRATA—*Fishes*—Flounder, Salmon, Shark.
  Amphibians—Frog, Newt.
  Reptiles—Turtle, Snake, Lizard.
  Birds—Eagle, Ostrich, Sea-gull, Sparrow.
  Mammals—Kangaroo, Lion, Ox, Whale, Ape, Man.

Functions of Living Creatures.—The simplest organism or the unit-mass of any living creature is merely a jelly-like speck made visible by means of the microscope. Part of the jelly-like substance may form a denser nucleus in the interior, and in some cases a tougher film is seen to surround and contain the whole. The organism is said to consist of a single cell. The jelly-like substance called *protoplasm* is a complex kind of matter, the precise nature of which is unknown, but it consists mainly of carbon, oxygen, and hydrogen, with minute quantities of nitrogen, sulphur, and phosphorus. Living protoplasm is continually undergoing two opposite sets of changes—building up or renewal, and breaking down or decay. The process of building up, which is distinctive of living creatures alone, involves nutrition or the taking in of food-substance, digestion or the elaboration of food, and assimilation or absorption into protoplasm. While this process goes on the organism grows by the assimilation of unlike substances, which are transformed into protoplasm and added to the mass from within and throughout. The simultaneous breaking-down process, on the most commonly accepted theory, is brought about by respiration or the absorption of oxygen. Protoplasm is an extremely unstable compound, always ready to combine with oxygen and break up into carbonic acid, water, and a very small proportion of a few other stable compounds. The living protoplasm is purified by the process of excretion, which is simply the thrusting out of the burnt products (carbonic acid, water, etc.) and of those parts of the food which escape digestion. When life ceases, protoplasm ceases to grow, oxidation continues unchecked, and the organism breaks up and decays away by slow combustion. In the process of growth, matter which is not living may be built into the substance. For example diatoms and radiolarians, which are single-celled organisms, form coats or skeletons of silica, and foraminifera, also consisting of one cell, secrete hard shells of carbonate of lime. All organisms, except the protoza and the simplest plants, consist of many cells containing protoplasm, built up into organs set apart for special purposes. These cells are usually supported in a framework of matter such as wood or bone, elaborated by the living organism and sharing its life for a time, but becoming practically lifeless as it grows older. When a cell grows, it increases in size to a certain limit and then divides into two cells, the process being termed *reproduction*. In the protozoa the division of a cell is complete separation, producing two individuals; but in higher organisms a single cell, termed an *ovum* or egg-cell, is separated from the rest, and grows by subdivision into a separate many-celled organism similar to the parent form. Most often, both in plants and animals, this liberated cell is unable to develop until it unites with a cell of another kind (termed a male cell) from the same species. Thus the continuance of the species is secured in spite of the death of the individual.

Constructive Plant Life.—Plants alone are able to raise inorganic substances, such as water, oxygen, carbonic acid, into the sphere of life-wrought or organic material. They cause the elements to combine into *proteids*, the raw material of protoplasm. This power in its entirety is confined to those plants which possess green leaves, and is exercised by them only when the energy of sunlight falls on the green colouring matter known as chlorophyll. Then the leaf is able to break up carbonic acid derived from the atmosphere, to restore the oxygen to the air, and cause the carbon to combine with the elements of water, forming starch which is at first stored up amongst the cells of the leaf. Subsequently the starch is transformed into sugar, which dissolves in the sap and is carried through the whole plant. On meeting the nitrates, sulphates, phosphates, and other salts of lime or potash, absorbed from the soil by the roots, the sugar combines with them, producing proteids and various waste products in a manner not yet discovered. The influence of green leaves on the air in sunlight is to unburn or decompose the carbonic acid. The solar energy used up in this work is converted into potential energy of chemical separation (p. 28), which is restored to the kinetic form when wood or coal unites with oxygen. The oxygen given out by the action of chlorophyll in the leaf laboratory is more than enough to supply the ceaseless respiration of the plant in daylight and darkness, so that, on the whole, green plants diminish the proportion of carbonic acid and increase that of oxygen in the air.

Destructive Animal Life.—Contrasted with the constructive processes of plants, changing lifeless into living matter and kinetic into potential energy, animals are wholly destructive. They cannot utilise solar energy, but derive all their power of doing work from oxidation of their own substance. They cannot manufacture proteids, so that all their food has to be prepared for them by plants. Animal life would indeed be impossible if plant life did not precede it. In their respiration animals are always removing oxygen and increasing the amount of carbonic acid in the atmosphere. Those plants which do not contain chlorophyll, such as the fungi, moulds, and bacteria, are as powerless as animals to manufacture food from carbonic acid and water. But unlike animals they have the power of manufacturing proteids if they obtain starch or sugar and the various salts amongst their food. Thus fungi—all the mushroom kind—grow abundantly only in decaying vegetable substance, which supplies plenty of starch. To sum up in a metaphor, the green plant, like a coal-laden steamer, conveys solar energy—using up some in the process—to the animal, which like a stationary steam-engine converts it into work.

Micro-organisms.—Minute one-celled organisms, chiefly plants in some ways allied to the fungi and moulds, known as bacteria, bacilli, microbes, or micro-organisms, play a very important part in the course of their life-history. One of these, known as the *nitrifying ferment*, changes the salts of ammonia derived from the atmosphere, or from decomposing animal matter, into nitric acid in the soil, thereby greatly facilitating the growth of plants. Another known as *yeast*, when cultivated in a weak solution of sugar, uses up some of the sugar, and changes the rest into carbonic acid and alcohol, hence it is extensively used in raising bread and in making wine and beer. Another changes alcohol in the presence of air into vinegar, and is extensively cultivated for that purpose. Special bacteria are now cultivated on a large scale, and employed in purifying sewage, ripening cheese, and assisting in various chemical operations. The spores, or young undeveloped cells, of many kinds of micro-organisms form a considerable part of the dust in the air, and are present everywhere. When these find a suitable place to grow in —for example, the blood or the tissues of a person not in strong health—they develop and multiply, producing by their vital processes certain poisons called toxins, which give rise to disease. Different species of micro-organisms have been detected as the cause of cholera, consumption, diphtheria, and many other maladies. The discovery of anti-toxins derived from the bacteria which produce the toxins has introduced a new method of medical treatment.

Evolution.—As the Earth, like other members of the solar system, is the result of a slowly unfolding series of changes; as the continents have by long and gradual degrees come to their present form, and are still undergoing alteration—so also living creatures display a progressive evolution. The classifications of plants and of animals are ascending scales, showing in each group a more complex structure and organs more distinctly set apart for special purposes. Amongst animals, for example, the protozoa have no organs at all; the single cell acts as a whole in every function. In the echinoderms, eyes and a separate stomach appear; in the arthropoda, limbs adapted for walking; and an internal skeleton connected to a backbone, and supporting the framework of the body, is only found in the vertebrata. Similar progressive advancement is to be found within each group, and even in the same species individuals vary so much that a regular gradation may often be traced into other species making it difficult to draw the dividing line. Transition types, such as Archæopteryx, a bird partly resembling a reptile, and the Australian duck-bill, which although a mammal has a beak like a bird and lays eggs, connect the different classes of animals, and similarly transition forms occur between the various kinds of plants. When the regular order of succession from lower to higher forms in plants and animals became apparent to biologists they were convinced that different species had not been created separately in different places, but had gradually developed in the course of ages from a common parent form. Charles Darwin and Alfred Russel Wallace almost simultaneously framed a theory to account for organic evolution—the gradual unfolding of the progressive design of plant and animal life; and the period of most rapid advance in modern biology dates from the publication of Darwin's *Origin of Species* in 1859. The original views of Darwin and Wallace are gradually being modified as new facts are encountered, and in particular the work of Weismann and Mendel, and of their followers, applying more exact statistical methods, give more prominence to variation in inherited qualities than to the effect of environment.

Heredity and Environment.—Darwin explained the origin of different species of living creatures by the two great influences of *heredity* and *environment*. As a rule the young of plants and animals resemble their parents, but no two are precisely like each other. General similarity is associated with small variations of structure. Sometimes these variations produce no influence on the life of the organism, and may pass unnoticed. But when they happen to make one individual better fitted for obtaining food or escaping danger than the others, that one has a better chance of living, thriving, and handing on its fortunate peculiarities to its descendants. If the variation of structure throws an individual out of harmony with its environment, making it weakly or stupid, that individual has a smaller chance of surviving and leaving offspring. According to Darwin's view, the constant struggle for life is always weeding out the weak and improving the position of the strong, leading by a process of natural selection to the survival of the fittest. But climate, and even the outline and configuration of the land, are not constant; hence organisms, hitherto victorious in the struggle for existence, may have to contend with an altered environment, and their development, according to natural selection, must after a time take place in a new direction with great sacrifice of life, and possibly the extinction of some species. This subject is far from simple, and is still in the stage of development in which the multitude of new details makes it difficult to present a clear view in simple language.

Conditions of Plant Distribution.—Plant life, as a rule, is most luxuriant where there is abundant sunlight, high temperature, copious rainfall, and soil abounding in the soluble salts necessary for nutrition. In the course of the ages plants have gradually been modified, so as to adapt themselves to their environment. Thus not only the comparative luxuriance, but also the habit and possibly the species of plants, depend to a large extent on the conditions of their growth. Where regions with different natural conditions meet, as, for example, on the sea-coast, on the slopes of a snow-clad mountain, or the edge of a desert, the kinds of creatures inhabiting the adjacent regions differ in a very marked way. If such barriers should come into existence in a region formerly of uniform configuration and climate, similar plants may become separated by quite different species adapted to the new conditions. While all animals are absolutely dependent on plants for food, some plants are in great part dependent on animals for their continued existence, and bright flowers, perfumes, and honey have an important office in attracting them. Insects especially carry pollen from one flower to another, and so secure cross-fertilisation, which greatly improves the quality of the seed.

Floral Zones.—Speaking widely, the luxuriance and variety of vegetation decrease from the equator to the poles, and from sea-level toward the summit of mountains. Fig. 65, adapted from Smirnoff's

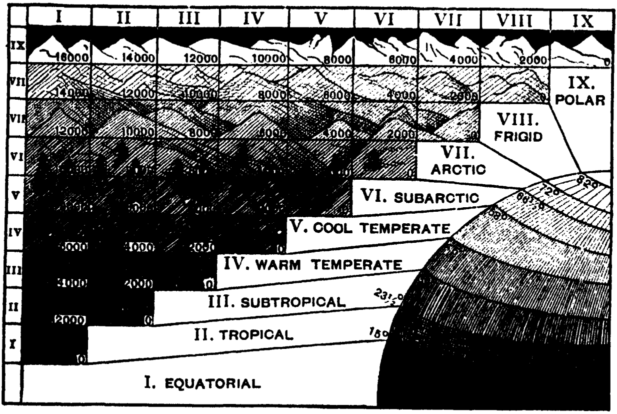

FIG. 65.—Zones of climate and vegetation in latitude and altitude (after Smirnoff).

Russian *Physical Geography*, represents a quadrant of the Earth's surface divided into climate zones at sea-level. The *Equatorial* zone corresponds to the region of maximum heat and rainfall; the *Tropical* to the region of maximum heat and small rainfall. The *Subtropical*, *Warm Temperate* and *Cool Temperate* zones show a gradual transition to the *Subarctic*, in which long cold winters produce a dwarfing effect on vegetation. The *Arctic* zone of stunted plants leads to the *Frigid*, and that to the unchanging ice-deserts of the *Polar* zone. The vertical columns represent slices of 2,000 feet of mountain-sides from the region above the snow-line (shown at the top of each column) down to sea-level. The horizontal rows show by their connecting lines at what average height the climate and vegetation corresponding to each of the sea-level zones is attained. Dr. Oscar Drude divides the Earth according to the affinities of its vegetation into three great divisions—the *Boreal* or Northern, the *Tropical*, and the *Austral* or Southern. In each one of these the species of plants are closely allied to each other, but distinct from those inhabiting the other divisions. The **Austral Group** includes the parts of the three southern continents south of the Tropic of Capricorn, and falls naturally into an *American*, *African*, and *Australian* division. The flora of Australia is unlike all the others; there are trees, such as the eucalyptus or gum-tree, which are evergreen but shed their bark yearly; the wattle (a kind of acacia) and the beef-tree, which bears long green branchlets instead of leaves. The **Tropical Group** extends from the Tropic of Capricorn northward to the Tropic of Cancer in America, to the centre of the Sahara in Africa, and to the Himalaya in Asia. It also contains three main divisions. Cinchona, mahogany, and the cactus are characteristic of the *American section;* the oil-palm, baobab, and giant euphorbias of the *African;* and teak, banyan, and sandal-wood of the *Oriental.* The **Boreal Group** is remarkable for the wide range of plants of similar species, such as the pine, birch and oak, over the *Northern division* in the three continents—in America north of the Great Divide, in Europe north of the southern peninsulas, in Asia the whole northern slopes. The other divisions of this group are the *Eastern Asiatic;* the *Central Asiatic*, comprising the vast plateau region; the *Mediterranean lands*, where the olive, mulberry, chestnut, orange and cork-oak flourish; and the *Central North American*, the natural home of maize, tobacco, and the giant pines of California.

Deserts.—In many respects Plate XVIII. gives the most interesting division of the Earth according to its vegetation. It shows three great barren zones forming broken girdles round the Earth, and covering, according to Mr. Ravenstein's calculation, more than 4,000,000 square miles. *Ice deserts* surround the North Pole, and are succeeded in the north of Europe, Asia, and America by a belt of frozen land called the *Tundra*, which thaws on the surface in summer and supports a growth of moss, grass and stunted shrubs. *Arid deserts* occur in all areas of great heat and very small rainfall. A northern zone includes the vast Sahara, the interior of Arabia, and Central Asia, terminating in the dreary Gobi, and the Great Basin of North America. Horny cactuses, the saxaul with foliage like wire, and the dull-grey sage-bush, are characteristic of the scanty plant life. A similar set of smaller deserts appears in the southern hemisphere, near the cooler but drier western sides of the continents, the Kalahari in Africa, the great Victoria Desert in Australia, and the small salt desert of Atacama in South America, forming links in the chain. Solar energy here falls on barren land, and, not being absorbed by plants, spends itself in the work of heating air (p. 137) and helping to maintain the permanent winds of the globe, which carry rain to more favoured regions. Thus in a sense the existence of fertile lands is a consequence of deserts. Treeless plains are common in all regions of scanty rainfall and great range of temperature, such as the borders of deserts. They occupy about 14,000,000 square miles of surface, covered with rich grass during part of the year, transformed into deserts of driving dust in the dry season, and flooded or covered with snow, according to the climate, during the rainy season or winter. The fertile *prairies* of North America, the *llanos* and *pampas* of South America, and the *steppe-lands* of Russia and Central Asia, are examples of such semi-deserts.

Tropical Forests.—When the grassy plains surrounding the tropical deserts on the equatorial side begin to receive a larger rainfall, bushes begin to break the monotony, and further on great forests are formed, the trees standing well apart at first, but growing closer as the heavy rains of the equatorial zone are approached. The densest forests naturally extend on both sides of the equator, where heat and rainfall unite to produce a paradise for plants. The *Selvas* of the Amazons, the darkest forests of the Congo and its tributaries, the forests of the Western Ghats of India, of the west coast of the Malay Peninsula, and of the islands of the Malay Archipelago, vie with each other as types of the utmost wealth of vegetation. Soft leafy canopies borne by lofty evergreen trees meet and intercept the light, so that no grass can grow in the dark depths of the woods, but climbing and twining plants innumerable, with stems like ropes or cables, force their way up on the trunks of their stouter rivals, and push on to expand their crown of leaves in the sunlight. The decaying vegetation below supplies abundant nourishment for pale-coloured parasitic plants, which, deprived of sunlight, have lost their chlorophyll and the power to manufacture food, and therefore live on their fellows.

Temperate Forests.—On the temperate side of the tropical deserts, the plains reaching into regions of moderate warmth and moderate rainfall become covered with less luxuriant but very extensive forests. These are most developed around the great lakes of North America, in Scandinavia, and as a broad belt from the Carpathians, north-eastward to the Baltic, eastward to the Ural Mountains, and beyond them across Asia north of 50° to the Pacific Ocean. In Western Europe the ancient forests—which appear to have once formed an unbroken belt across all the northern continents—have been cut down and the land cultivated. The warm temperate forests are composed of deciduous trees, that is, trees whose leaves wither and drop each autumn, the leaf laboratories being dismantled in the comparatively sunless months. Oak, beech, elm, ash, lime, and many other kinds of forest tree, are found in their greatest luxuriance in this zone. Toward the pole, where the winters are longer and more severe, the deciduous trees vanish, the hardy birch, with its silvery bark, reaching farthest north. Pines and firs, clad in small, hard, needle-shaped leaves, can alone resist the climate, and vast forests of these characterise the subarctic zone and the higher slopes of mountains.

Animals and their Life Conditions.—The life conditions of some of the marine animals of most importance from the physiographical standpoint have already been touched on (pp. 223-232). Amongst all animals the struggle for life is harder, or at least more apparent, than with plants, the stronger hunting down and devouring the weaker. Animals in their native haunts should therefore be inconspicuous if they are not to attract the attention of their enemies, or to arouse the suspicion of their prey. Almost all fishes, and many caterpillars, rapidly assume the colour of their surroundings. The hare and ptarmigan, living amongst the brown heather of northern hillsides in summer, are brown in fur or plumage, but in winter, when the land is white with snow, their colour also changes to white, and they remain inconspicuous in their new surroundings. This periodical adaptation to environment, which is common in Arctic animals, is one of the causes which have led to the preservation of the race. Some insects are so like withered leaves or twigs that even an experienced eye is often deceived by them. Strange resemblances have also been traced out between entirely different species of animals; and since the similarity is always brought about by the weaker or inferior type assuming the appearance of the stronger or superior, almost as if of purpose to impose on enemies, it is called *mimicry*.

Faunal Realms.—Animals exhibit more marked peculiarities of distribution than do plants. Similar forms are usually, though by no means always, found in like conditions. The *fauna*, or collection of animals, of each one of the northern continents bears a close resemblance to that of the others; while the *faunæ* of the three southern continents are similar in a much less degree, and, as a rule, totally unlike those of the northern. The most generally accepted division of the Earth into realms occupied by different faunæ is that suggested by Dr. P. L. Sclater, shown in Plate XIX. The names adopted for these divisions or realms are—the *Palæarctic* or Old Northern, the *Ethiopian*, the *Oriental*, the *Nearctic* or New Northern, the *Neotropical* or New Tropical, and the *Australian*. Professor Heilprin, another eminent authority, preferred to class the Palæarctic and Nearctic realms together, on account of their general similarity, as the *Holarctic* or Entire Northern. He also recognised a region of transition to the Neotropical realm occupying the south of North America, and another of much greater extent forming a transition to the Ethiopian and Oriental realms and including the whole Mediterranean region.

Northern Realms.—In both the Old and the New Northern realms the white polar bear frequents the Arctic snow-deserts. Farther south occur reindeer and elks, bears—black, brown or grizzly—foxes, wolves, beavers, hares and squirrels, and the bison, now almost extinct in Europe and only preserved by Government protection in America. The representatives of various families become more unlike each other toward the southern border. Moles, rats and mice, badgers, sheep and goats, camel and the yak, are confined naturally to the Palæarctic realm. On the other hand, the musk-ox, skunk, prairie dog, racoon, and jumping mouse are exclusively restricted to the Nearctic realm. Compared with the southern realms, those of the north are remarkable for the high place in the scale of development occupied by their most common animals. But the very complete study of the fossil forms of life preserved in the rocks shows that in past ages the northern lands were inhabited by a gradually developing series of more primitive types, from which the existing creatures are evidently descended.

Ethiopian Realm.—Africa, south of the Sahara, and Arabia contain few or none of the animals which make their home round the Mediterranean at the present time. There are no wolves, foxes, bears, or tigers, the flesh-eating animals being represented by the lion, "the king of beasts," the leopard, panther, hyæna, and jackal. This purely tropical realm is the exclusive home of the hippopotamus and the giraffe, tallest of living animals. The elephant and rhinoceros are common also to the Oriental realm. Swift-footed, graceful and fantastically striped zebras and quaggas frequent the grassy plains. Of all African animals the most widespread and characteristic are the antelopes, which gallop in vast herds over the plains, and, ranging in size from an ox to a rabbit, inhabit bush, forest, and desert as well. Apes—narrow-nosed, tailless creatures of the monkey kind—are very common in all parts of the continent. The equatorial forests are the home of the most highly developed and fiercest apes, the gorillas and chimpanzees. The ostrich, the largest bird now existing, is typical of Africa, being found in all the open plains and deserts both in the north and south. The adjacent island of Madagascar contains very few of the animals common in the Ethiopian realm, but abounds in lemurs.

Neotropical Realm.—South America is richer in varieties of animal life than any other realm, and it is also peculiar for the very large number of species which are found nowhere else. The true monkeys are confined to the great forests, where they swarm in amazing numbers. They differ from the African and Oriental apes mainly in having a broad nose and a long prehensile tail, by which they swing from branch to branch. Vampires and others of the leaf-nosed bats, the rabbit-like chinchilla of the Andes slopes, the beaver-like coypu rat of the plains, and the little agouti, allied to the guinea-pig, are all exclusively South American. So are the more peculiar sloths which swing back downward from the trees, the great bushy-tailed ant-eaters with long, slimy tongues specially modified to lick up ants, and the curious armour-clad armadilloes resembling in their habits the hedgehogs of Europe. Although no bears, foxes, or wolves penetrate south of the transition zone, the jaguar, resembling in many respects the tiger of the Oriental realm, ranges over the entire continent, and the puma or American lion even extends far into North America. The llama, alpaca, and vicuna, confined to the upper slopes of the Andes, are closely allied to the camel family, which inhabits only the Palæarctic realm. Neotropical birds are numerous and distinctive, ranging in size from the huge unsightly condor to gem-like humming-birds, which are smaller than many insects. The rhea of the southern plains belongs to the ostrich family, but, as a whole, the bird-fauna of South America is more allied to the Oriental than to the Ethiopian.

Oriental Realm.—Animals common in the Palæarctic and the Ethiopian regions meet together in the Oriental realm, and give it a characteristically mixed fauna. Lions, leopards, rhinoceroses, and elephants, almost or quite identical with those of Africa, are found along with bears, wild dogs, foxes, and the true deer so distinctive of Northern Eurasia. Lemurs akin to those of Madagascar are abundant in the south, and the mixture is completed by tapirs and many birds with strong South American affinities. The tiger is peculiar to the Oriental realm, but ranges from Java northward within the borders of the Palæarctic as far as Sakhalin, and is curiously enough absent from Ceylon and Borneo. This realm abounds in squirrels, mice, bats, and, together with some Ethiopian forms of apes, it affords a home in Borneo to the man-like oran-outan. Although to north and west the Oriental merges gradually into other realms it has a sharp boundary to the south-east, where Wallace in his exploration of the Malay Archipelago found the Oriental species, even of birds and insects, stop at a line drawn between the small islands of Bali and Lombok, and thence between Borneo and Celebes south of the Philippines. Celebes, however, seems to be occupied by a transition fauna.

Australian Realm.—So peculiar and so distinctive is the fauna of Australia and the surrounding islands that many naturalists class it as a main division opposed to all the rest of the globe. Except the dingo or native dog, which may have been introduced by man, the flying foxes (of the bat family), and some birds, none of the animals of other realms occur in it. Their place is taken by the least developed of mammals, the monotremes, of which the duck-bill is the type, and the marsupials, represented by the kangaroo. Opossums, living in trees, are the only Australian form of animals, and indeed the only marsupial, found in other continents, a few species occurring in America. The emu and cassowary are allied to the ostrich family; the bower-bird, which delights in laying out the ground in front of its nest like a garden ornamented with pebbles and flowers, cockatoos, and the black swan are characteristic birds. Australian animals are found in all the islands of the Archipelago northward and westward to Celebes and Lombok.

Island Life.—From Wallace's researches in the Malay Archipelago it appears that an entirely different fauna and a largely different flora may live on adjacent islands in identical physical conditions. He considers that the islands on the Australian side of the dividing line have not been united with those of the Asiatic side since the fossil marsupials of the northern hemisphere were alive. It is equally evident that the islands of Lombok and Celebes have been connected with Australia and that Bali and Borneo have been connected with Asia by land which has been submerged so recently that the organisms have not yet had time to be much modified from the type of their continental contemporaries. Similarity of fauna between the Malay Archipelago and South America, and many resemblances in the flora of the three southern continents, indicate the probability of a former Antarctic land connection right round the world, which is not contradicted by the configuration of the bed of the Southern Ocean. Purely oceanic islands are usually inhabited only by species which might have been conveyed by sea from the nearest continent, and often contain very remarkable modified forms.

Action of Living Creatures on the Earth.—The processes of erosion by which the scenery of the continents has assumed its present form are largely modified by the action of living creatures. Corals and other marine organisms are powerful agents in rock-making. Forests, and the growth of vegetation generally, bind the soil together, preventing denudation on mountain slopes, reclaiming alluvial terraces in rivers, and often putting a stop to the drift of sand-dunes. Vegetation also affects *climate*, producing a uniform rainfall, checking evaporation, and regulating the flow of rivers by absorbing the water of heavy rain, avoiding sudden floods, and by keeping up continuous oozing in dry weather, preventing the streams from dwindling away. Disintegrating action is on the whole more frequent. The roots of plants and the little root-like fibres of lichens serve as wedges, splitting up rocks and aiding the formation of soil. Earthworms, termites, and ants aid largely in mixing and pulverising the ingredients of the soil. Boring molluscs drive long narrow holes into the rocks below sea-level, and enable the breakers to produce a much more rapid disintegration of the cliffs than would be possible otherwise. Crayfishes, burrowing under the banks of rivers, are important agents in causing changes in the direction of the stream and the position of its beds. Beavers have a strange instinct of felling trees and constructing dams across streams to provide an expanse of water in which to build their "lodges." These dams serve to accumulate a head of water, and when burst by a flood the destructive force of the current works great changes on surface scenery. There is no living creature, large or small, which does not leave some trace of its life-work impressed upon the solid globe, and although the individual result of the action of most creatures may be little, the sum of the life of the globe is a very potent factor in the evolution of the conditions which ultimately determine it.

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CHAPTER XVIII

MAN IN NATURE

Man as an Animal.—One genus of the animal kingdom separates itself from the rest in a manner so complete as to require special consideration. It is the genus to which we ourselves belong, and it contains the one species—Mankind. Varieties of this species differ so much amongst themselves physically that the gap between the most highly developed and the most degraded is not incomparable with that between the latter and some of the most developed apes. Organic evolution seems liable to no exception at this point. Mankind is subject to the same natural conditions as other animals, being dependent, directly or indirectly, on plant life for food, and always under the control of heredity and environment. In some respects the human species is inferior to the less developed animals, particularly in the possession of a thin skin without fur or feathers, and in the absence of claws, tusks, or other specialised weapons of defence.

Man as Man.—The differences between Man and the lower animals are so numerous, definite, and distinctive that until within very recent times they obscured, even in scientific minds, the full significance of the similarities. There are no limits to the geographical distribution of the species. Men can live in all the continents, and from the equator to the poles. Although the contrast between Man and other animals becomes more distinct amongst the higher members of the human species, it may be traced in all. It is less of degree than of kind, and is rather intellectual and spiritual than physical. The use of reason with the associated power of language, the recognition of a Creator, and as a necessary consequence the sense of religious duty, are distinctly human attributes. As these powers become developed, strengthened, and purified, Man advances in the scale of being, independently of his physical development. Heredity and environment acquire new importance, and indeed their existence and potency were first recognised by the way in which birth and education determine the higher powers of the mind. The intellectual as well as the physical unity of the human species is strikingly shown by the fact that even amongst the most advanced peoples there are individuals who exhibit the untamed instincts of the savage, while in the most degraded tribes individuals with some higher powers and finer feelings occasionally rise above the level of the rest. By the use of reason mankind is able to modify or choose its environment, and thus, consciously or unconsciously, to direct the course of development. This power gives to the individual man far greater influence and independence than is exercised by individuals of any other species.

Civilisation may be looked on as the result of men using their power of changing their natural surroundings, and regulating their natural wishes or impulses in order to increase the well-being of the community to which they belong. Each variety of the human species appears to be capable of attaining a certain degree of mastery over themselves and their surroundings, this degree being much higher in the case of some varieties than in others. The position occupied by different groups of the human species with respect to civilisation is intimately connected with their conceptions of religion. Tribes of the lowest civilisation live, as a rule, in a state of vague fear of evil spirits and of the ghosts of their ancestors, which they try to appease by worship and sacrifices. They believe that the spirits dwell in natural objects or in rude idols (*fetishes*), to which they accordingly pay great respect. More civilised peoples, reasoning on the appearances of Nature, are *Polytheists*, or believers in many separate gods, to whom the creation and control of different parts of Nature is ascribed. *Pantheism* (illustrated by Buddism) is a development of Polytheism, from which it differs in conceiving God to be present everywhere, and all existing things, Man included, to form part of Him. The highest and most civilised races are *Monotheists*, recognising one God, who created the World and directs its processes. Three forms of Monotheism are prevalent—the Jewish, in which the Old Testament is held as a divine revelation; the Christian, all sections of which accept also the teachings of the New Testament; and the Mohammedan, following the Koran, a book compiled from the Jewish and Christian Scriptures by Mohammed.

Environment and Man.—External conditions do much to determine Man's position in the scale of civilisation. It is a matter of dispute whether the different races of mankind result merely from the different conditions in which they have developed, or if changes consequent on moral advancement or degradation have had a large share in producing them. The races lowest in civilisation are most completely slaves to their environment, exercising only the animal powers. Where the climate makes clothing unnecessary, and abundant fruit-bearing plants supply the means of life without labour or forethought, as in some tropical countries, mankind is found in the least developed or most degraded form. On the other hand, when natural conditions are very hard, the climate severe, and the means of life only to be obtained by chance or success in hunting or fishing, the development of intelligence appears to stop short when the prime necessaries—food, clothing and shelter—are secured. The fur-clad Eskimo, feeding on blubber in his ingeniously-constructed snow house, is certainly an advance on the naked, homeless savage of the tropics, who satisfies his hunger with fruits and insects. But both are so exclusively fitted to their environment that the Eskimo pines by the Mediterranean, and the forest Pygmy sickens and dies in the sunlit grass-lands. Intellectual development appears to be stimulated by conditions which make life neither too easy nor too hard. In temperate regions, necessitating shelter and warm clothing, where there is a regular succession of seasons, forethought and thrift are encouraged by the need of providing in summer for the coming winter. Ingenuity has to be exercised in evading the effects alike of heat and cold, and the skill thus acquired finds additional employment in providing ornaments and luxuries to gratify an awakened and cultivated taste. Strength and self-reliance come from the successful struggle with adverse conditions, and many of the characteristics of nations are due as much to the nature of the land they dwell in as to the inherent qualities of the race. Mountaineers of every race are hardier, more independent, and more attached to their native land than the dwellers on low inland plains, who, on the other hand, work more, excel in perseverance, and are as a rule more successful in obtaining a sufficiency of the means of life. Seafaring peoples, compelled to be continually watching for signs of change in weather, and often called upon to decide quickly and act promptly in circumstances of danger, acquire a distinctive steadiness of nerve and quickness of resource which lead to a general advance in civilisation. Climate and scenery exercise a powerful influence on moral as well as on physical conditions. By contrasting the stolid earnestness and ceaseless exertion of the dwellers in Northern Europe with the passionate vivacity and intermittent activity of Southerners, an ingenious author once went so far as to assert that *Character is a function of latitude.* The poetry and the religious systems of all peoples are closely connected with the nature of their land. Patriotism also is a quality derived from the same source, and is shown most intensely by peoples long settled on small but clearly characterised natural regions. The tendency of civilisation is gradually to modify the influence of environment, widening the field of view from that of the family or tribe to that of all mankind, and merging love of the native country into a cosmopolitan appreciation of all the lands of the world.

Races of Man.—Certain distinct types of mankind may be easily recognised, but the transition between them is so gradual that it is almost impossible to draw the dividing line. Students of Ethnology form classes of mankind partly by taking account of physical resemblance and difference, partly by considering the nature of the languages spoken. Following Professor Keane, we may group mankind around three main centres, corresponding respectively to the Black, Yellow, and White types of humanity. The table expresses some of the larger groups, with a selection of illustrative races:—

BLACK		YELLOW		WHITE	
Western	Negro Bantu	Mongol-Tatar	Kalmuck Kirghiz	Aryan	Kelt Teuton Slav Hindu
Negrito		Tibeto-Chinese			
Eastern	Papuan Australian	Finno-Ugrian	Eskimo Lapp Magyar	Semitic	Arab Jew
		Malayo-Polynesian	Malay Maori	Hamitic	Berber Somali
		American		Caucasic	

Black Type.—This represents the least civilised peoples, and around it is grouped about one-seventh of the World's population. As the name implies, the complexion is black or dark brown. The hair, also black, is woolly or frizzled, and each hair has an extremely characteristic form, resembling a minute flat ribbon. Most of the people of the Black type are tall and powerful, often with well-formed bodies, but with wide flat noses, thick lips, and projecting jaws. They are naturally sensual and unintellectual, like children they are usually happy, light-hearted, and careless, but are subject to moods of depression and outbursts of appalling cruelty. They inhabit the tropics exclusively, except where their ancestors have been removed as slaves to warm temperate regions. As a rule, in their own lands they go nearly unclothed, living by hunting or by cattle-rearing, and, in rare cases, following a primitive agriculture. The religion professed is usually a low form of Nature-worship, characterised by fetishism and the practice of witchcraft. Mohammedanism makes rapid headway amongst some of the tribes, but Christianity seems less adapted to the nature of the Black type. The *Negro* tribes occupying the Sudan region of Africa are the most typical examples. The brown-skinned *Bantus*, inhabiting the whole of the Great African Plateau, are best known in the Zulu nation of the South. The eastern division of the Black type includes the frizzly-headed *Papuans*, or natives of New Guinea, and the *Australian Aborigines*, who, while probably the lowest race in point of civilisation, differ from the typical Black and approach the White in possessing abundant wavy hair and a full beard. The *Negritoes*, or "Little Negroes," are difficult to classify. They are usually small of stature and of slight mental power. The best representatives are the Pygmies of the Central African forests, the nearly extinct Bushmen of South Africa, and the diminutive natives of the Andaman Islands.

Yellow Type.—People grouped around the Yellow type make up considerably more than one-third of the World's inhabitants. Their complexion varies from clear yellow to coppery brown, and typically they have a small nose, frequently upturned, and narrow, slit-like eyes. Their hair is black, coarse, and straight, and each hair forms a minute circular tube. They are usually under the middle height, and although often of slight physical strength they have great powers of endurance, and are, as a rule, very laborious workers. Intellectually they show a fair degree of civilisation, and in many instances have attained considerable success in science and in art. Conceit and apathy are characteristic mental qualities. They are usually Polytheists and worshippers of ancestors; many are Buddhists, and a considerable number Mohammedans. Finns and Magyars, inhabiting Finland and Hungary, are included under the Yellow type only on account of the nature of their language; physically and intellectually they are indistinguishable from the highest members of the White type. The *Tibeto-Chinese* are possessed of an ancient civilisation, and, although typically conservative and antagonistic to change, they are now following the example of the Japanese, a branch of the same race which has in recent years entered fully into the current of that civilisation which was formerly associated with the White type. The greater part of Asia is peopled by tribes of the Yellow type of a relatively high civilisation, now approximating to that of the higher races of the White type. Except where seafaring has called forth their powers, the people inhabiting the tropical Malay Archipelago are as a rule ignorant and uncivilised, although far above the level of the degraded peoples of the Black type. The Maoris of New Zealand, belonging to the *Malayo-Polynesian* section, contrast strongly with the Australian blacks. The *American* section shows some well-marked differences from the other representatives of the Yellow type. Their coppery complexion won for them the name of Red Indians in the days when the first Europeans reached America and believed it to be part of Asia. From the Arctic Circle to Cape Horn the race is, in its essential features, the same, although the degree of civilisation attained varies. In the hot forests of the Amazon they range as tribes of naked savages, as low in the scale as the African blacks. On the northern prairies they formed nations of hardy warriors, brave in battle and inconceivably cruel to their captured foes, living by hunting, but scorning work, and now dwindling away before the white settlers. The highest native American civilisation had its seat on the temperate plateau of Mexico and in the Andes valleys; and although the strongly organised native empires of the Aztecs and the Incas were destroyed by the Spaniards in the sixteenth century, the "Indian" element has always remained of importance, and appears even to be gaining ground in the countries of that region.

White Type.—The leading physical peculiarities of this type are a prominent and highly arched forehead and abundant wavy hair, the cross-section of each hair being oval. Dark skins, almost approaching those of the Black type, occur in the Hamitic section, but the complexion of the White races is usually fair and ruddy. The White type is the centre of a more numerous group of mankind than either of the others, and intellectually it is the most advanced. Religion has its fullest and purest forms of expression, science has been studied to best purpose, the fine arts have been raised to the highest perfection amongst them. Enterprise in commerce and valour in war are equally pronounced, and at the present time the White type, particularly the Aryan races spreading from Western Eurasia, dominate the world. The classification given in the table is founded mainly on affinities of language. The *Aryan* group, for example, includes the speakers of the Aryan or Indo-Germanic languages, all of which contain many words of common derivation, notwithstanding the differences between English, German, Danish, Spanish, French, Italian, Latin, Greek, Russian, Persian, and Sanscrit. Consequently it was assumed by Professor Max Müller and other philologists that the races using these languages were also descended from a common ancestry.

People of Europe. — Professor Huxley showed that, so far as the peoples of Europe are concerned, it is impossible to reconcile the linguistic with the physical classification. He pointed out that the difference between the Teutonic-speaking nations of Britain, Germany, Holland, and Scandinavia; the Romanic-speaking people of Spain, Portugal, Italy, France, and Rumania; the Slavonic-speaking people of Servia, Bulgaria, and Russia; and even the Magyar and Finnish-speaking people of Hungary, Finland, and Lapland, do not warrant a scientific classification by language. He recognised two extreme types of Europeans, which are rarely found pure, and occur mixed together in varying proportions in all parts of the continent. The first type is that of tall men, averaging about 5 feet 8 inches in height, with long heads, fair complexions, yellow or light brown hair, and blue eyes. Such people are most abundant in the north, round the coasts of the Baltic, and their character is typically solid, trustworthy, persevering, and deliberate. The second type is that of a shorter race, averaging about 5 feet 5 inches in height, with rounded heads, swarthy complexions, black or dark brown hair and eyes. They are most numerous in the south bordering on the Mediterranean. Their prevailing character is impulsive and enthusiastic; they are passionate, inconstant, and fond of ease. These two types evidently represent different races; but they have mingled so thoroughly that any attempt at exact classification is now impossible, although some indefinite but very interesting subdivisions have been made out.

Distribution of the Human Race.—The estimated population of the world is 1,600,000,000 people. These are all dependent for their means of life on the land, and the densest population, that is the greatest number living on a given area, is necessarily found where the land is richest in useful productions. Deserts are practically unpeopled; the few inhabitants live on the produce of the date-trees of the oases and on the aid given them by passing caravans to which the oases afford invaluable halting-places

Steppe-lands can carry more inhabitants, who, as a rule, are wandering shepherds feeding their flocks on the best grass they can find, and moving on to "pastures new" when the ground is cropped bare. Well-watered lands, when naturally treeless, or after the trees have been cleared, yield to agriculture abundance of food and material for clothing; hence such countries can support many inhabitants. The crowded Nile delta, the river plains of China, and the valley of the Ganges are the most densely peopled parts of the Earth, on account of the fertility of the ever-renewed soil, allowing large crops of food-plants to be raised at moderate expense. The question of the production of food is the most important in order to find how many people a given country can support. Mr. Ravenstein calculated that with proper treatment of the land about 6,000,000,000 inhabitants should be comfortably provided for on the Earth, a number which, if the present rate of increase continues, will be attained in less than 200 years. There are other wants besides food, and by the division of labour made possible by the organisation of civilised life, a large population may be engaged in working mines or carrying on manufactures in regions where sufficient food for them cannot be grown. The supply of bread and meat is kept up by trade with their fellow-workers on lands yielding a superabundance. Western Europe has a dense population on this account. Traffic, or carrying commodities to and fro, gives rise, at points where a change of routes or means of conveyance occur, to a local concentration of population, and thus trading towns arise at harbours, fords, and the intersection of roads or railways.

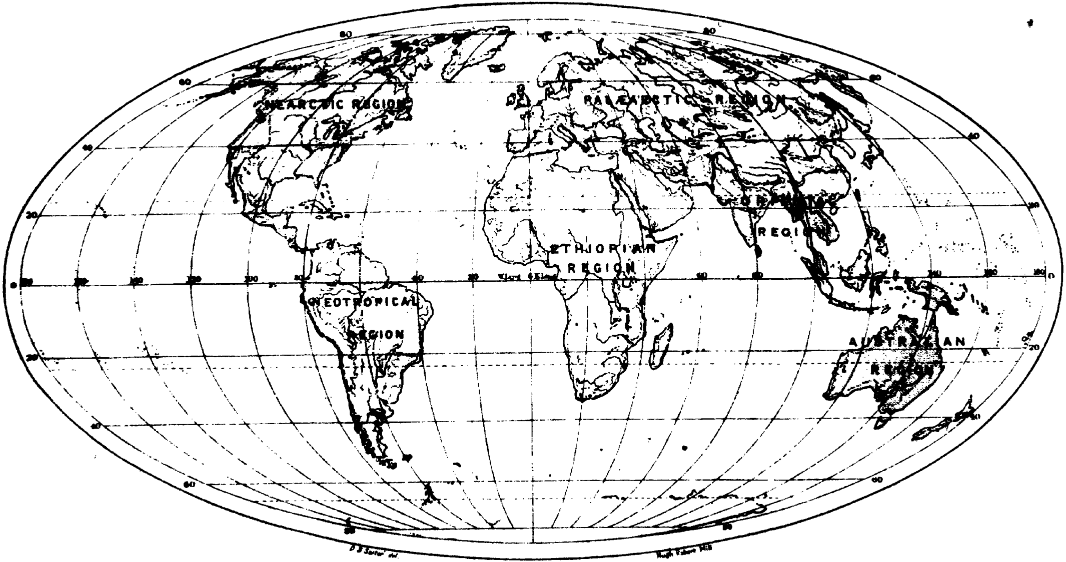
Centrifugal Migration.—In a primitive state of society the migration of tribes is not unlike the migration of the lower animals, being directed from regions in which the means of life no longer suffice for the inhabitants. They are of the nature of evictions. A much larger population formerly resided in Central Asia, the margin of the Gobi Desert being lined with remains of ruined cities; but the desiccation of the continent drove the people outward into whatever lands afforded food for their cattle or plunder on which to live. The people against whom the hordes of wanderers were driven were in turn dispersed in all directions, and the disturbance spread throughout every part of Eurasia. Overcrowding in countries of dense population also necessitates migration to more thinly peopled regions; but here, as a rule, the human power of discrimination and choice regulates the resulting movement. Lands are sought out which afford similar natural conditions to those in which the emigrants have formerly lived, and promise an easier or more prosperous life than the overcrowded country could offer. Thus the people of North-western Europe, and particularly of the British Islands, have thronged in millions to North America, and in hundreds of thousands to South Africa, and Australasia; while numbers of the people of Southern Europe have migrated to South America and Northern Africa. Another form of centrifugal migration is the voluntary exile of people persecuted for holding particular religious or political opinions. The settlement of New England by the Puritans, of Maryland by Irish Roman Catholics, and of Utah by the Mormons, illustrates the action of this principle.

Centripetal Migrations have exercised an extraordinary influence in modern times. They are the result of attraction rather than repulsion, and take place toward, and not from, a special region. The most potent magnet is gold. This led the Spaniards to Mexico and South America on the discovery of the new continent. In 1849 the discovery of gold in California caused a rush of fortune-seekers from all parts of the world, and led to the very rapid settlement of the Pacific coast of North America. Victoria was the scene of a similar rush in 1850 the Transvaal in 1887, Western Australia in 1893, and the inhospitable and almost inaccessible upper waters of the Yukon in 1897. Diamonds have had a like effect in attracting a large population to Kimberley, in Cape Colony. In most cases many of the people attracted by the abundance of precious and portable products remain after these cease to be readily available, in order to develop the agricultural resources of the land. Coal-fields and regions where petroleum or natural gas abound now rapidly attract a large population, on account of the facilities afforded for carrying on manufactures of every kind. Rich agricultural lands, such as those of the north-west of North America or the west of Argentina, also give rise to concentration of population from all sides, when means are provided by railways or rivers to carry the wheat or other farm produce to a profitable market.

Geography has to do with the relations between regions and races. Physiography in so far as it takes account of the human race is concerned with the study of Man in relation to the Earth, while Geography treats of the Earth in its relation to Man. The branch of geography dealing with the useful or desirable things which occur in or on the Earth's crust, and the effects which the discovery, production, transport, and exchange of these have on mankind is known as commercial Geography. Communities of civilised people associated together under one government form nations, and the definite region of the Earth's surface occupied by a nation is called a country. Countries have sometimes arisen from the centrifugal or centripetal migration of peoples under natural influences; but more commonly their limits have acquired their present position by the conquest or loss of territory in struggles against neighbouring nations. Wars carried on by kings or governments, frequently without the consent of the people concerned, have drawn most of the boundary lines on "political" maps. Historical Geography concerns itself with tracing out the changes in the

BIOLOGICAL REGIONS.

After Sclater and A. R. Wallace



extent of territory exclusively occupied or controlled by each nation at different times.

Man's Power in Nature.—Man more than any other animal leads a destructive life. The use of wood in construction and for fuel enables him to destroy forests so rapidly that in comparison the depredations of beavers and all other animals are insignificant. The need for communication between distant parts of the Earth has produced considerable changes in the configuration of coasts and in the distribution of land and water. Plants and animals also have been modified by cultivation, and their natural limits of distribution entirely altered. Much of Man's power in Nature is evasive. It consists in devising methods of utilising natural phenomena for the purpose of escaping uncomfortable consequences. Thus the invention of the umbrella and of the sun-helmet give a certain amount of independence of the weather; still more the methods of heating, cooling, and lighting houses. Lightning conductors reduce the risk to which life and property are exposed in a thunderstorm; knowledge of the laws of cyclone-motion often enables sailors to escape the fury of a storm. Steam- and internal combustion-engines on land and sea, and above all electric telegraphy with or without wires, deprive wide tracts of the Earth's surface of their natural influence as barriers. But in every case natural powers are not overcome; they are merely utilised.

Geographical Changes.—When land becomes valuable it is often profitable to reclaim ground from the sea. This is done along the flat coasts of most civilised countries, and to an unequalled extent in Holland, where most of the people actually live below sea-level. The sea is kept out by a great system of artificial dykes and regulated sand-dunes, while continual pumping by steam or wind power keeps the water-tight compartments of the reclaimed land dry. On the other hand, there have been projects for flooding the sunk plains of arid regions, so as to provide new sea-routes, or modify desert climate by the presence of a sheet of water. Examples of these are the proposal to admit the Mediterranean and Red Sea to the great Jordan Rift Valley, in order to open a new sea-route to India; and the suggestion of admitting the Mediterranean water to some of the shotts of the northern Sahara. Land-masses necessitating long sea-routes have frequently been severed by artificial channels, of which the Suez and the Panama Canals are the most remarkable examples. The Kiel Canal across Jutland leads from the North Sea to the Baltic; a French ship-canal has been projected to join the Bay of Biscay and the Mediterranean north of the Pyrenees; a Greek canal has severed the isthmus of Corinth: and a series of canals avoids the Falls of Niagara and other obstructions between the great American lakes. Rivers are continually being interfered with, their mouths deepened into harbours, their course levelled into canals, the current split up into irrigation channels, or diverted bodily to prevent floods, or to furnish a route for railways. The greatest project of river diversion ever proposed is that of a Russian engineer to restore the Oxus to its ancient bed and bring it into the Caspian once more, thus affording a water-way from Europe to Central Asia. Tunnels such as those through the Alps, through the Khojak Hills in North-western India, and under rivers or arms of the sea, as in the case of the Mersey, the Severn, and the Hudson, are other examples of geographical changes wrought by human power. So too are the subsidences which follow mining operations, especially in the case of salt mines, as in Cheshire. These often form lakes and sometimes alter the direction of streams.

Biological Changes.—By diligent cultivation and careful selection the food-grains of the modern farmer have been produced from various species of wild grasses, which naturally had small and innutritious seeds. In like manner many varieties of animals have been obtained by careful breeding, which are specially fitted for the use of man. Without his interference they would never have existed. Savage or useless creatures have been exterminated over wide areas, and useful forms of life introduced in their place. Sheep are now far more numerous in Australia and temperate South America than any indigenous species of mammal ever was. Human interference can never overcome, but only take advantage of, natural conditions; and the rabbits accidentally introduced to Australia happened to be so much in harmony with their new surroundings that they have thriven and multiplied, so as to be an intolerable plague in some districts. By human agencies the horse, dog, sheep, and cow are no longer confined to any faunal realm, and the useful plants of each of the continents have been transplanted wherever suitable conditions are found in all the others. Potatoes, maize, and tobacco brighten the fields of Europe, while wheat, sugar-cane, and coffee spread over vast expanses of America. The American cinchona and the Australian eucalyptus are now invaluable to the fever-haunted lands of India, and the latter tree flourishes in the swampy lowlands of the Mediterranean, while the vine and olive gladden the heart of the Australians and South Americans.

Meteorological Changes.—The regulating effect of vegetation on rivers is probably accompanied by an actual increase in the rainfall of wooded as compared with barren regions. This is one of the reasons why in many of the treeless plains of North America and Australia tree-planting is encouraged by the institution of an annual holiday called Arbor Day, on which each citizen is expected to plant a tree. In Russia the cutting of trees was prohibited in the whole belt of forests which covers the Ural-Carpathian ridge, whence all the rivers of Eastern Europe flow to north and south. Palestine presents a striking example of climate altered by human action. In the days of the Israelites the steep mountain slopes were terraced artificially by walls supporting a narrow strip of soil, on which grain, vines, olives, and fruit trees of many kinds were grown. The rainfall is supposed to have been regular and gentle; and after percolating through the terraces, formed perennial springs at the foot of the slopes, feeding the brooks which rippled through the valleys. Now by neglect the terraces have been broken down, and the soil is all swept into the valleys. The mountain sides, being bare and rocky, allow the occasional heavy showers to dash down in impetuous torrents to flood temporary streams, which, when the rain passes, give place to channels of dry stones. The land becomes baked in the fierce rays of the sun by day, and chilled by intense radiation through the clear dry air at night, the range of temperature having increased as the rainfall diminished. To a less degree the more efficient drainage of hill pastures in the rural districts of the British Isles has deprived the streams of the steady supply of water stored in boggy ground, and has made the rivers subject to more severe floods and droughts.

Man and the Degradation of Energy.—Men are continually at work altering the distribution of matter and energy on the Earth. Gold is sought for in all lands, and accumulated in enormous quantities in London, Paris, Berlin, New York, and other towns. Diamonds are more numerous in Amsterdam than in Africa, India, or Brazil; and so with other mineral commodities. The salts and the combined nitrogen of the soil on which its fertility depends are being removed by every crop of wheat, to be ultimately cast as useless sewage into the sea. Land deprived of its salts ceases to yield profitable crops; the natural process of restoration by weathering is too slow, and manures, which every year are becoming scarcer, must be sought far and near to replace them. No animal but man is so improvident. All others restore the mineral constituents to the land from which they gathered their food, and so insure a continuous supply. The potential energy laboriously stored in growing trees is destroyed by reckless timber-cutting and the use of wood as fuel. The accumulated savings of energy stored up in coal are being expended in every industrial occupation, and coal is rapidly becoming scarcer. Every consumption of energy, except that of the regular income of solar radiation, is impoverishing the Earth, and accelerating the natural process of the degradation of Energy. The great steamer, driving its giant bulk across the ocean at 30 miles an hour, consumes as much potential energy in every revolution of the propeller as served in former days for the stately clipper, rising and dipping over the crests of the sea under the impulse of the sun-driven winds, to make the whole journey. The internal combustion engine, if driven by the explosion of alcohol vapour or some other volatile product of vegetation, would prove far more economical than any engine depending on mineral fuel, for the supply could be renewed every year in inexhaustible quantity. Tidal power, already utilised to some extent, and likely to be made use of increasingly, simply does work off the energy of the Earth's rotation, and, although in a very minute degree, its employment hastens the time when Earth and Moon will have the same period of rotation. Similarly, all processes now proudly being increased in power and speed dissipate ever faster the wealth of potential energy that Nature lays up at an ever-diminishing rate. Sun, wind, and water power, and the Earth's store of internal heat, are the only non-wasteful sources of work. It is significant that the most recent industrial applications of electricity to work machinery, as, for example, in the factories near the Falls of Niagara, and the aluminium works at the Falls of Foyers and on Loch Leven in Scotland, and on Snowdon in Wales, utilise energy in this non-wasteful manner. Nothing is given for nothing, and even the knowledge revealed by the scientific study of Nature, that the power for effecting these processes will not last for ever, has been dearly bought. Since the true part played by energy has been understood in fact, though possibly not in name, the governments of all civilised nations have exerted themselves to encourage economical processes of manufacture, satisfactory systems of agriculture, intelligent methods of sewage disposal, and particularly to ensure the continuance, and if possible the increase, of the forests of the world, on which its prosperity, and even its habitability, largely depend.

Man's Place in Nature.—The grand distinction between Man and other creatures is that he can take advantage of his environment, so as to modify his development in any desired direction. He need not, except wilfully, drift before the wind of natural changes, but can sail close up to it like a well-handled ship. Man's higher nature can, and in many cases does, completely control his lower or animal existence. The sense of moral duty overcomes even the first law of animal nature—the preservation of life; it reverses the struggle for existence by substituting the principle of self-sacrifice, on which the stronger protects, instead of destroys, the weaker. Man, when most truly human, or in the highest attained stage of the evolution of civilisation, ceases to be in harmony with the system of Nature in the sense true of the lower animals—

> "Know, man hath all which Nature hath, but more,
> And in that *more* lie all his hopes of good.
> Nature is cruel, man is sick of blood;
> Nature is stubborn, man would fain adore;
>
> "Nature is fickle, man hath need of rest;
> Nature forgives no debt, and fears no grave;
> Man would be mild, and with safe conscience blest.
>
> "Man must begin, know this, where Nature ends:
> Nature and man can never be fast friends,
> Fool, if thou can'st not pass her, rest her slave!"

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APPENDIX I

SOME IMPORTANT INSTRUMENTS

Weights and Measures.—Standard measures called "weights" are used in a balance in order to find the mass of any body of convenient size by weighing it, that is by finding how many of the standard masses are attracted by the Earth with the same force as the body of unknown mass is attracted. The standard masses may be of any size or form, provided they can be easily obtained, and new ones exactly equal to them made if the originals be lost. Grains of seed were once used for this purpose, but now the standards are usually made of a metal which does not alter in the air. When a standard is once accepted it does not matter how it originated, as copies are always made by actual weighing. The British unit mass or pound avoirdupois is divided into 7000 grains, or 16 ounces, and 2240 pounds are called a ton. In the United States the same unit pound is used, but 2000 of them are called a short ton, the term long ton being used for the ton of 2240 pounds. In English-speaking countries the way in which masses are calculated is very contradictory and puzzling; but almost all other civilised nations employ the metric system, the unit mass of which is the kilogramme (equal to about 2¼ lbs.) divided into 1000 grammes, and the gramme is similarly divided into 10 decigrammes, or 100 centigrammes, or 1000 milligrammes. These standards of mass are used by scientific men in every country. The unit of length amongst English-speaking people is the yard, divided into 3 feet of 12 inches each, and 1760 yards are called a mile, although the sea-mile or mean minute of latitude contains rather more than 2000 yards. Measures on the *metric system* are, like the weights, subdivided decimally. The unit is the metre (about 39⅜ inches), divided into 10 decimetres or 100 centimetres or 1000 millimetres; and for measuring long distances 1000 metres are called a kilometre. It is convenient to remember that 25 millimetres are nearly equal to 1 inch, or, more exactly, that 33 centimetres are equal to 13 inches, and that 8 kilometres are equal to 5 miles. The measures of volume fluid ounces, pints, gallons, bushels, cubic inches, cubic feet, used in English-speaking countries, are as confused as the other standards, while the unit volume of 1 litre (about 1¾ pints), divided into 1000 cubic centimetres, is as convenient as the other parts of the metric system. The only connection between the British systems of weights and measures is that the gallon is fixed as the volume of 10 lbs. of pure water at 60° F. Relations of a much more intimate kind pervade the metric system. It is true that the metre is not quite the length originally intended, which was $\frac{1}{10000000}$ of a quadrant of the Earth's meridian, but the litre is a cube 1 decimetre in the side, and the kilogramme is the mass of 1 litre of pure water at 4° C., the gramme being similarly equal to the mass of 1 cubic centimetre of water at the maximum density point. Notwithstanding the simplicity and convenience of the metric system, it was considered advisable in this book to make use of the familiar British units in order to present the facts of science in the manner most easily grasped by English-speaking people.

Angular Measurement.—The simplest instrument for measuring angles is a circle divided on the circumference into 360 equal parts or degrees, each degree being subdivided into as many equal parts as the size of the circle permits. Some means must be provided for sighting the objects whose angular distance is to be measured, and this may be simply done by having a small telescope fixed on one of the diameters of the circle. If the circle is pivoted on its centre the telescope can be pointed in turn to different objects by rotating the circle, and the amount of rotation gives the angular distance between the objects. To measure this there must be a fixed point outside the circle. If the degree mark on the circle opposite this fixed point is read off when the telescope points to the first object, and again when it points to the second object, the difference between the two readings is the angular distance between the two objects measured from the centre of the circle. Instruments constructed on this principle can be made of almost any degree of accuracy by increasing the size of the circle, the fineness of the divisions on the edge, and the precision of the centring. In the transit circles used in astronomical observations the highest degree of precision is aimed at, the scale of divisions being read by means of a microscope, and adjustments provided to compensate for any difference of level between the points on which the circle turns, produced by changes of temperature or other causes. In the theodolite (Fig. 66), used by surveyors in constructing maps or laying out engineering works, two circles are used, one horizontal, *H h*, the other vertical, *V v*, and the instrument is set by means of levelling screws, *l l l*, and two spirit levels, *s s*, each time that it is used.

The horizontal circle in this case is fixed, and the amount of horizontal turning of the telescope is measured from points engraved on the verniers attached to the supports bearing the telescope as shown at *H*. The movement of the vertical circle, which turns with the telescope, is measured from verniers *V v* attached to the telescope supports. An instrument of this nature is sometimes called an altazimuth, as by means of it both the altitude and the azimuth or compass bearing may be measured.

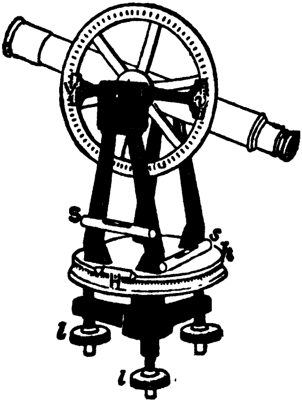

Fig. 66. — Diagrammatic sketch of Theodolite, showing the method of measuring angular distances both horizontally and vertically.

By such an instrument the most accurate determinations of latitude and longitude may be made by a traveller on land. At sea, where it is impossible to use a theodolite on account of the motion of the ship, angles are measured by means of the sextant. This, as the name implies, is a graduated arc one-sixth the circumference of a circle. The frame A (Fig. 67) has a handle at the back not shown. The arc B is divided into degrees and minutes; it usually subtends at its centre 70°, but is graduated in 140 equal divisions which correspond to degrees of measurement. At the apex of the frame is pivoted the *index bar* D, bearing at one end a vernier C, which reads on the arc, and at the other end a plane mirror E called the *index glass*, perpendicular to the plane of the frame and rigidly attached to the index bar. To one radius of the frame is attached a fixed plane glass F called the *horizon glass*, perpendicular to the plane of the frame and parallel to the index glass when the index is at zero. The half of the horizon glass next to the frame is silvered, the other half being clear. The other radius of the frame supports the *telescope* G, the axis of which is parallel to the plane of the frame. The telescope is so directed that the index glass can be seen by reflection in the silvered portion of the horizon glass, whilst at the same time an object can be seen through the clear half. The angle subtended by two objects, one of which is seen directly through the horizon glass, and the other by double reflection from the index glass and the horizon glass, is twice the angle between the two mirrors.

Thus, from the method of graduation adopted on the arc, the angular distance may be read directly on the arc. To use the sextant on land it is necessary to have a horizontal mirror, called an artificial horizon, placed upon the ground, as the natural horizon cannot be used on account of the irregularities of the land surface.

The Mariner's Compass consists of a magnetised steel needle, or a series of such needles fixed parallel to each other, delicately pivoted in a box, which is loaded with lead and hung so as to remain horizontal in spite of the tossing of a ship. A light circular card is fixed above the needles, and moves with them. The point over the north-seeking end of the needle is marked as the North, the opposite point is marked South, and the ends of the diameter at right angles East and West. The edge of the card is divided into 360 degrees, there being 90 in each quadrant, *i.e.* from N. to E. or from E. to S. The exact direction or bearing of a distant object may be stated as N. 45° E. if it appears midway between the north and east points of the horizon as estimated from the card. Sailors have another way of expressing direction. They divide the edge of the card into thirty-two "points," each containing 11¼ degrees, but divided into halves and quarters. For each point they have a special name; thus the quadrant from North to East is divided into *North*, *North by East*, *North-North-East*, *North-East by North*, *North-East*, *North-East by East*, *East-North-East*, *East by North*, *East;* and so on round the card. (*See* compass in Plate I., where each alternate point is named.) The indications of the compass require to be corrected for variation, and also for the local attraction of the vessel; in order to be as free as possible from which the standard compass is usually carried on the top of a high pole rising above the highest part of the deck.

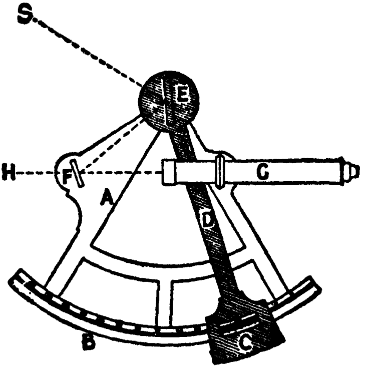

FIG. 67.—Diagrammatic sketch of a Sextant, showing the method of measuring angular distances in any direction.

A complicated form of gyroscope driven at a very high speed by an electric motor, and resisted in its movements in a special manner, has been constructed to point always to the north thus forming a compass without a magnetic needle, and dispensing with all adjustments for local magnetism.

Barometers and Barographs.—The simple mercury-tube and cistern mounted in a metal case is the most accurate form of barometer. The height of the mercury in the tube is measured either to the fiftieth of a millimetre or to the thousandth of an inch by means of a vernier, due allowance being made for the change of level in the cistern as well as in the tube of mercury. In comparing atmospheric pressure at different stations it is necessary to correct the reading to some standard temperature (always 32° F. or 0° C.), because when mercury is heated it expands, its density becomes less, and a slightly higher column would be supported by the same atmospheric pressure. A correction for gravity, or rather for gravity and centrifugal force combined, must also be made, as a column of mercury weighs less at the equator than near the poles. Sir Napier Shaw introduced a unit which is independent of gravity. This is the *millibar* or one-thousandth of the mean pressure of the atmosphere. Mercurial barometers can be graduated in this unit by taking 1 millibar as equal to ·03 in. For popular purposes a barometer is sometimes made to show its rise or fall by the movement of a pointer round a dial, the change of quarter of an inch in level of the mercury being thus magnified on the dial to an inch or so. Self-recording barometers of several types are used in observatories. The simplest in principle (Fig. 68) produces a photographic record by a beam of parallel light from a lamp passing through the upper part of the tube *ac*, and falling on a cylinder *a′c′* covered with photographic paper, and revolving once in twenty-four hours by means of clockwork. The paper opposite the clear space is blackened by the light, and Fig. 68 shows the sort of record left by a barometer rising irregularly, the height of which at any given moment can be estimated by seeing how much of the paper *b′c′* was shielded from light by the mercury *bc* in the tube. The portable aneroid barometer consists essentially of a metal box with an elastic top and exhausted of air. When the atmospheric pressure increases the top is forced in, when it diminishes the top curves out, and this movement is transmitted by suitable mechanism to a hand moving round a dial, or to a lever carrying a pen which records the

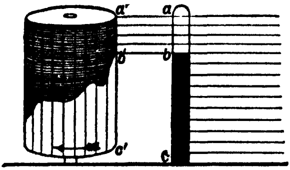

FIG. 68.—Photographic Barograph. (Diagrammatic View.)

fluctuations of pressure in a curve drawn in ink on a rotating cylinder. "Inches" and fractions are marked round the dial by comparison of the aneroid with a mercurial barometer, and a scale of heights is usually added, for aneroids are of most value in hill-climbing and aeronautics. For a complete discussion of the use of aneroids in measuring heights, and of the errors of the aneroid as an instrument, the student is referred to Mr. Whymper's work, *How to use the Aneroid Barometer*, published by Mr. Murray.

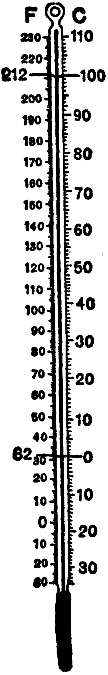

FIG. 69.—Mercurial Thermometer.

Thermometers are instruments for measuring temperature by means of the difference of expansion of a gas or liquid and the glass vessel containing it. Mercury is usually employed as the liquid, because it has a low specific heat, great conducting power, expands considerably when heated, has a low melting-point and a high boiling-point. A mercurial thermometer consists of a globular or cylindrical bulb (Fig. 69), and a long tube of extremely small bore, which has been sealed while filled with boiling mercury, so that, after cooling, the bulb and part of the tube contain mercury, and the remainder is a vacuum. The freezing and boiling points of any liquid depend only on the pressure, and if the pressure remains unchanged the liquid always freezes at one definite temperature, and always boils at one definite temperature. Thermometers are graduated by plunging them bodily into melting ice, and after the mercury has contracted to the full, marking its position by a scratch on the glass; then by hanging them in the vapour of boiling water at ordinary atmospheric pressure, and when the mercury has expanded to the full, marking its new position by a scratch. Between the two fixed points any kind of subdivision might be made, but only three ways of dividing the space into "degrees" or steps are in use. On the *Centigrade* scale (often erroneously named after Celsius) the freezing-point is marked 0, the boiling-point 100, and the space between is divided into 100 equal degrees, which are continued above 100 and below 0 as far as may be necessary (C, Fig. 69). On *Fahrenheit's* scale, used popularly in English-speaking countries, the freezing-point is called 32, the boiling-point 212, the space between being divided into 180 equal degrees, which are continued downward and upward (F, Fig. 69). On the *Reaumur* scale, used popularly in Germany and Russia, the space between freezing and boiling-point is divided into 80 degrees. The Centigrade scale is used in scientific work all over the world, except for meteorological observations in English-speaking countries, for which the Fahrenheit scale has hitherto been held to present too many advantages to be discarded. In some of the publications of the British Meteorological Office, temperatures are now given in Centigrade degrees reckoned from absolute zero, 273° C. below the freezing-point of water. It is convenient to remember a quick way of translating Centigrade into Fahrenheit degrees. *Multiply by 2, subtract one-tenth of the result, and add* 32. For example, to translate 15° C., $15 \times 2 = 30$, subtracting one-tenth $30 - 3 = 27$, adding $27 + 32 = 59°$ F. Since mercury freezes at -40 (a temperature which happens to be expressed by the same figure on both Centigrade and Fahrenheit scales), alcohol thermometers are used for measuring lower temperatures, such as those of the winter at Verkhoyansk. No two common thermometers read exactly alike, and those employed for accurate observations are always compared with standard instruments (at the National Physical Laboratory for the United Kingdom), and have their errors ascertained and allowed for. Thermometers of special construction are employed for different purposes, such as the registration of maximum and minimum temperatures of air, the intensity of solar radiation, the temperature of the body, the height of mountains, by showing the exact boiling-point of water at diminished pressures, etc. In observing the temperature of the air, screens or ventilated boxes are required to protect the thermometer from the direct heat of the sun, while admiting a free current of air. **Thermographs** are constructed on the principle of the barograph, to furnish a continuous record of changes of temperature. **Deep-sea thermometers** require to be protected against the pressure at great depths by surrounding the bulb by a glass sheath partly filled with mercury or other liquid. They are constructed either to leave an index sticking in the tube at the points of highest and lowest temperature encountered while submerged, or to be inverted by appropriate mechanism, and so caused to register the temperature at any given point. A third method consists in raising a sample of water from the depth at which the temperature is desired by means of a vessel constructed in such a way that it is insulated as regards temperature changes, so that when the sample is brought up, its original temperature may be read by an ordinary thermometer.

The temperature of the upper air is ascertained by means of very light registering thermometers sent up attached to kites or free balloons. These thermometers are constructed on the principle of the expansion or contraction of a metallic strip or tube.

Hygrometers measure the amount of water-vapour in the atmosphere by finding either at what rate the air is taking up vapour by evaporation at its actual temperature, or how far the air must be cooled in order that its vapour may be saturated. The commonest form consists of two thermometers placed side by side, the bulb of one being left dry, while that of the other is covered by a piece of fine muslin, and kept wet by a thread dipping into a vessel of water. The farther the vapour of the air is from saturation the more rapid is the evaporation from the wet bulb, and, since evaporation withdraws heat, the temperature shown by the wet-bulb thermometer is lower than that shown by the dry. The greater the difference between the readings of the two, the smaller is the relative humidity of the atmosphere, the exact value of which for each difference of temperature has been calculated and recorded in tables. Dew-point hygrometers, in various forms, invented by Regnault, Daniel, Dines and others, consist of a polished surface, the temperature of which can be lowered by evaporating a liquid, or by a current of iced water, until a film of moisture is condensed from the air. The temperature at which condensation takes place is that of the dew-point, at which the vapour of the air becomes saturated, and a table of the vapour-pressure of saturated vapour at different temperatures gives the absolute humidity.

Rainfall is measured by ascertaining to what depth the rain would cover the ground on which it falls, supposing that none were to evaporate, soak in, or flow away. The simplest and best form of rain-gauge is that known as the Snowdon, which consists of a metal cylinder, the top of which is an accurately turned brass ring, 5 inches in diameter, set perfectly level. The rain which passes through this ring is conducted into a glass bottle, and the lower part of the rain-gauge, containing this bottle, is sunk in the ground, so that the temperature changes little, and evaporation is checked. The amount of water collected is measured daily at 9 A.M., by pouring the contents of the bottle into a tall narrow glass jar graduated on the side into divisions, each of which represents a depth of one-hundredth of an inch or one-fifth of a millimetre of rain on the ground. The diagram (Fig. 70) shows a section of the Snowdon rain-gauge, which is uniformly fixed with its rim one foot above the surface of the ground in the British Isles. In other countries different standard heights are employed.

Self-recording rain-gauges are constructed on two main principles. In one the water, as it is collected, runs into a narrow chamber in which there is a float carrying a vertical rod with a pen at its upper end. As the level of the water rises in the chamber, the pen rises on a sheet of paper carried by a rotating cylinder, and so registers the duration and intensity of the rainfall. A siphon or other automatic device is often used to empty the chamber, when a certain amount has been collected, and the pen is thus brought back to zero. On the other principle the water is collected in a counterpoised bucket, so adjusted as to descend uniformly as the amount received increases, and the descent is registered by means of a pen in the usual way. When the bucket is full it overbalances automatically, and as it rises the pen goes back to zero. Full particulars as to the method of observing rainfall and forms for entering the record are sent post free to any inquirer by the Director of the British Rainfall Organization, Meteorological Office, Air Ministry, Kingsway, London, W.C.

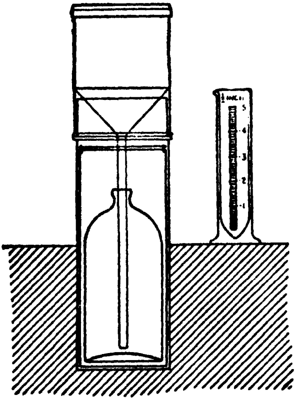

Fig. 70.—Section of Snowdon Rain-gauge and measuring glass. The shading represents the ground in which the rain-gauge is sunk, leaving its rim one foot above the surface.

Anemometers, or instruments for measuring the force of the wind, are constructed either to record velocity or pressure. To show velocity a series of hollow metal cups, mounted on a light pivoted frame, are caused to revolve by the wind, and each revolution is registered by an arrangement like that of a gas-meter. Experiment shows what ratio the speed of the revolving cups bears to that of the wind. In the earlier forms of pressure anemometers the wind blows against a large flat surface, the pressure exerted on which is indicated by the tension of spiral springs. In Dines's anemometer the pressure and velocity of the wind are measured by the changes of pressure produced in a tube by the wind blowing across the open end. These instruments, like all others for measuring phenomena subject to constant variation, can be made to write a continuous record on a revolving cylinder. From such a record the exact direction, force and velocity of the wind may be ascertained at any moment.

Deep-sea Soundings.—The depth of calm water, when less than 200 fathoms, can easily be found by letting down a lead weighing 7 lbs. by a line marked at regular intervals. The impact of the lead on the bottom may usually be felt, and the line ceases to run out, or at any rate, if too much line is let out, a sudden increase in weight is felt when, on hauling it in, the lead is lifted off the bottom. At great depths a very heavy sinker must be used: its impact on the bottom cannot be felt, and the line runs out steadily. In making a deep sounding, the line—usually a fine steel wire—may be marked at every 100 or 50 fathoms, and the intervals of time at which each mark disappears in the water carefully noted. On account of the increasing resistance of the water on the lengthening line the time interval lengthens gradually and uniformly; but when the sinker reaches the bottom there is an abrupt increase in the time taken for the next 50 fathoms to run out, which is sufficient to assure the officer in charge that bottom is reached. A more convenient method is to run the wire over a measuring wheel with an indicator recording the number of revolutions, and supplied with a brake which stops the machine automatically when the bottom is reached. From depths of 3000 to 4000 fathoms no ordinary line or wire is strong enough to haul up the heavy sinkers, which accordingly are so constructed as to detach themselves after driving the brass "sounding tube" to which they were attached deep into the floor of the ocean, where it is filled with the deposit which lies there, and whence it can readily be raised to the surface.

APPENDIX II

CURVES AND MAPS

Graphic Representations.—Self-recording instruments, like the barograph and thermograph, write their records as continuous curves, which present to the eye a vivid picture of the nature and extent of these changes. The daily and annual changes of temperature and pressure are represented in the form of curves in Figs. 23, 24, and 28. When any one of the conditions under consideration varies uniformly, the curve form of expression can be used; thus Fig. 27 shows temperature at different latitudes, where position on the Earth varies uniformly, and Fig. 35 shows temperature at various depths in the sea, where depth varies uniformly. The highest point of a curve or any convex bend is called a maximum, the lowest point, or any concave bend, a minimum; and a line drawn horizontally, so that the curve cuts off an equal area above and below, is called its mean. It is simply a matter of convenience that the space representing a degree of temperature, and that representing an hour, a day, a fathom, or a degree of latitude, should have the same length in a diagram. In the sections of oceans and continents there is a natural relation between heights and lengths; but if on a section of Asia 100 miles of length were represented by an inch, the greatest height of the continent would be shown by one-twentieth of an inch, and would scarcely be visible. Accordingly, heights are drawn on a much larger scale, and the steepness of the slope is exaggerated in the same proportion, while the positions and relative amounts of change of level are brought vividly before the eye. It would be an excellent exercise for the student to reduce these sections to a true scale, either by reducing the heights on the paper to one-three-hundredth of their height (but this is scarcely possible), or by keeping them unchanged, and lengthening the whole section, or a part of it, three hundred times. This would give the true average slopes of the continents and oceans.

Maps.—The plan or map of a room is simply an exact drawing of the outline of the floor, and the spaces occupied by each article of furniture, drawn so that one inch or any other definite length on the paper corresponds to one foot on the floor. The ratio of the lengths is called the scale of the map; thus the scale of a map in which one inch represents one foot is 1 : 12; the maps of counties on the Ordnance Survey of the United Kingdom are drawn on the scale of six inches to one mile, or 1 : 10,560; those of the country generally, in which one inch stands for one mile, are on the scale of 1 : 63,360; Plates IX. and X. represent the British Islands on the scale of 1 : 8,500,000; and Plates III.-VIII., etc., show the Earth on the scale of 1 : 150,000,000 along the equator. In the case of the plan of a room, the map, if increased twelve times in length and breadth, would make a carpet accurately fitting the floor, with spaces marked for the furniture to rest on; but if the map of the British Islands were magnified 8,500,000 times each way, it would not fit the country exactly, because the Earth's surface is curved, and a flat sheet cannot lie smoothly on a curved surface without being folded or stretched. In the case of the Earth as a whole, this difficulty of representing the whole surface in its true form and proportions is much greater. The surface of the sphere cannot be spread out flat, and many devices—termed projections—are adopted to represent it with as little distortion as possible. On "*Mercator's projection*," shown in Plate I., the parallels of latitude are shown as straight lines, the equator being unbent from a ring into a rod, so that we can see all round it at one glance. The other parallels are not only unbent, but stretched to the same length as the equator, so that the meridians become parallel straight lines, and, in latitude 60°, are just twice as far apart as they should be. In order to preserve the correct outline of the land, and to make the *directions* measured on the map correct, the parallels are not placed equidistant, but stretched out toward the poles, the degrees of latitude increasing in length in the same proportion as the degrees of longitude. Thus different parts of the map are on different scales; one square inch including Greenland, for example, represents only one-tenth of the area which one square inch including India comprises. It resembles a cylindrical projection, which may be supposed to be drawn on a great sheet wrapped round the globe, as shown in Fig. 71. Mercator's projection, although much less distorted than the true cylindrical projection of Fig. 71, is useless for comparing areas. But it is of unique value, because a line drawn between any two points cuts all the meridians at the true angle, and it is therefore much used in navigation. Plate II. and all the other maps of the world shown in this volume are drawn on *Mollweide's equal area* *projection*, the advantages of which are that it shows the whole surface of the globe in one view, and that one square inch in any part of the map represents the same number of square miles.

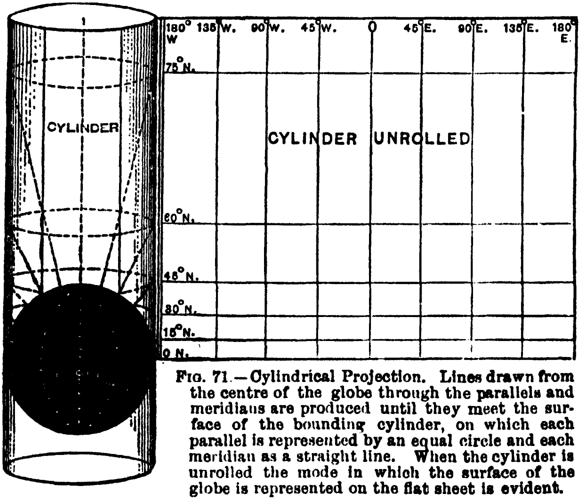

Fig. 71.—Cylindrical Projection. Lines drawn from the centre of the globe through the parallels and meridians are produced until they meet the surface of the bounding cylinder, on which each parallel is represented by an equal circle and each meridian as a straight line. When the cylinder is unrolled the mode in which the surface of the globe is represented on the flat sheet is evident.

This fits it for the comparison of the area occupied by any distribution. It has the drawback of distorting the forms of the land in high latitudes; but the true form and area can only be shown together on a *globe* which is a true model of the Earth. In maps of the world in hemispheres the meridians are shown converging to the poles, and there is an infinite number of projections employed for special purposes. Maps of a small area can be more accurately shown on a *conical projection*. Those of the British Islands (Plates IX. X., etc.), for example, are on a conical projection; the meridians converging to the proper degree and the parallels being arcs of circles. If a cone of transparent paper were placed over an artificial globe (Fig. 72) and the lines traced through, a map of this kind would result; the distortion being greatest at the greatest distances from the parallel along which the cone touched. When the cone is supposed to cut the globe along two parallels, the resulting map is much more accurate. In actual map-making the distance and curvature of the parallels and meridians for each projection are ascertained by mathematical calculations.

Contour-lines are drawn on maps to express differences of level in an exact manner. They express the height of the land in the same way as isotherms express the temperature. Each contour-line represents a string of figures of elevation having the same value. The sea-coast is a natural contour-line, and raised beaches, if the land has been elevated without disturbance, are natural contour-lines etched on the hill-sides. Every contour-line represents the coast-line that would result, if the sea rose to that level. When contour-lines are far apart the gradient or slope is gentle; for example, along AB (Fig. 73) we could advance nine divisions of the scale before the elevation became 500 feet lower, but along AC this difference of height is reached in three divisions of the scale, or the slope is three times as steep and the contour-lines are much closer. The student, if residing in the United Kingdom, should procure and carefully study the Ordnance Survey maps (contoured) on the half-inch, one-inch and six-inch scales for his own locality. The half-inch layer map of the Ordnance Survey, and Bartholomew's half-inch maps of Great Britain present a pictorial relief of the land in which the main features of hill and dale stand out with great distinctness. The Ordnance maps may be obtained through most post offices, and any bookseller may order them direct from the Ordnance Survey Office, Southampton. Mountains

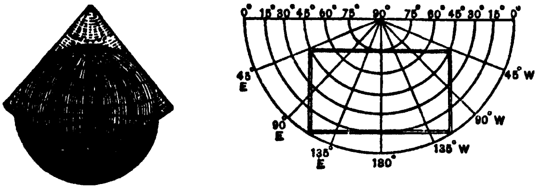

FIG. 72.—Conical Projection. The left-hand figure represents a cone placed on the globe, the surface features of which are projected, as in Fig. 71, by lines drawn from the centre. The right-hand figure shows the cone unrolled showing the parallels as semicircles and meridians radiating from a centre. The double lines show a map cut from the developed cone.

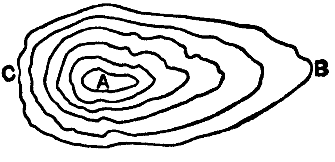

FIG. 73.—Contour-lines. The line B C represents sea-level, each of the inner lines represents a level 100 feet higher than that next to it on the outside, the line round A being 500 feet above the sea. The scale below refers to horizontal distance.

and watersheds are frequently represented on maps by shading in certain conventional ways, so as to bring out the general appearance of the surface.

It must be remembered that maps are not merely pictures or diagrams, but are in fact apparatus designed for the purpose of quantitative representation by which exact measurements may be made. Most of those given in this volume are specially compiled from a great number of sources in order to combine the records of many researches which were previously available only in separate publications.

APPENDIX III

DERIVATIONS OF SCIENTIFIC TERMS

Aberration. L. *ab*, from; *erro*, to wander
Absorption. L. *ab*, from; *sorbeo*, to suck in
Agglomeration. L. *ad*, to; *glomus*, a ball
Agonic. Gr. *a*, not; *gonia*, a corner or angle
Amorphous. Gr. *a*, not; *morphe*, form
Amplitude. L. *amplitudo*, largeness
Analysis. Gr. *ana*, up; *luo*, to loosen
Anemometer. Gr. *anemos*, wind; *metron*, measure
Aneroid. Gr. *a*, not; *neros*, liquid
Annular. L. *annulus*, a ring
Anticline. Gr. *anti*, against: *klino*, to lean or incline
Anticyclone. Gr. *anti*, opposite to, and Cyclone
Aphelion. Gr. *apo*, from; *helios*, the sun
Approximation. L. *ad*, to; *proximus*, nearest
Aqueous. L. *aqua*, water
Arc. L. *arcus*, a bow
Archæan. Gr. *archaios*, ancient
Archæopteryx. Gr. *archaios*, ancient; *pterux*, wing
Argon. Gr. *a*, not; *ergon*, work (i.e. *inert*)
Arthropoda. Gr. *arthros*, a joint; *pous*, foot
Asteroid. Gr. *aster*, star; *eidos*, form
Atmosphere. Gr. *atmos*, air; *sphaira*, a sphere
Aurora. L., the goddess of dawn
Austral. L. *auster*, the south wind, southern
Axis (*pl.* axes), L., an axle
Azote. Gr, *a*, not; *zao*, to live

Barograph. Gr. *baros*, weight; *grapho*, to write
Barometer. Gr. *baros*, weight; *metron*, measure
Biology. Gr. *bios*, life; *logos*, a discourse
Bisect. L. *bis*, twice; *seco*, to cut (to divide into two equal parts
Boreal. L. *boreas*, the north wind, northern
Botany. Gr. *botane*, herb or plant

Cainozoic. Gr. *kainos*, recent; *zoe*, life

Calcareous, L. *calcarius*, chalky
Capillarity, L. *capillus*, hair
Carposporeæ, Gr. *karpos*, fruit; *sporos*, seed
Centrifugal, L. *centrum*, centre; *fugio*, to flee from
Centripetal, L. *centrum*, centre; *peto*, to seek
Chlorophyll, Gr. *chloros*, pale green; *phullon*, leaf
Chromosphere, Gr. *chroma*, colour; *sphaira*, a sphere
Chronometer, Gr. *chronos*, time; *metron*, measure
Cirrus, L. cirrus, a curl
Cœlenterata, Gr. *koilos*, hollow; *enteron*, bowel
Cohesion, L. *co*, together; *hæreo*, to stick
Comet, Gr. *kometes*, long-haired
Complement, L. *complementum*, that which fills up
Concentric, L. *con*, with; *centrum*, centre (having same centre)
Conduction, L. *con*, together; *duco*, to lead
Constellation, L. *con*, together; *stella*, a star
Convection, L. *con*, together; *veho* (*vectum*), to carry
Cretaceous, L. *creta*, chalk
Cryptogam, Gr. *kruptos*, concealed; *gamos*, marriage
Cumulus, L. *cumulus*, a heap
Cyclone, Gr. *kuklos*, a circle

Datum (*pl.* data), L. *do* (*datum*), to give
Deciduous, L. *deciduus*, falling off
Desiccation, L. *desicco*, to dry up
Detritus, L. *de*, off; *tero* (*tritus*), to rub
Devitrification, L. *de* from; *vitrum*, glass; *facio*, to make
Diameter, Gr. *dia*, through; *metron*, a measure
Dicotyledon, Gr. *duo*, two; *kotuledon*, a cup(-shaped leaf)
Discrete, L. *discretus*, separate

Echinodermata, Gr. *echinos*, hedgehog (spiny); *derma*, skin
Elasticity, Gr. *elauno* (*elaso*), to drive
Electricity, Gr. *elektron*, amber (by rubbing which electric phenomena were first observed)
Ellipsoid, Gr. *en*, in; *leipo*, to leave; *eidos*, form
Eocene, Gr. *eos*, dawn; *kainos*, recent
Equator, L. *æquus*, equal
Equisitineæ, L *equus*, horse; *seta*, bristle
Erosion, L. *e*, away; *rodo*, to gnaw
Escarpment, Fr. *escarper*, to cut down steeply
Estuary, L *æstuare*, to boil up; *i.e.* tumultuous tides
Ethnology, Gr. *ethnos*, a nation; *logos*, a discourse
Evolution, L. *e*, out; *volvo* (*volutum*), to roll
Experiment, L. *experior*, to try thoroughly

Fauna, animals supposed to be protected by the *Fauns*, or rural gods

Filicineæ, L. *filix*, a fern
Flora, L. *flos*, a flower
Foraminifera, L. *foramina*, openings ; *fero*, to carry
Fossil, L. *fossilis*, that which is dug up

Genus (*pl.* genera), L. *genus*, birth (related by birth, of one kin
Geography, Gr. *ge*, the earth ; *grapho*, to describe
Geoid, Gr. *ge*, the earth ; *eidos*, form
Geology, Gr. *ge*, the earth : *logos*, a discourse
Glacier, Fr. *glace*, ice
Glauconite, Gr. *glaukos*, bluish grey
Gravitation, L. *gravis*, heavy
Gymnosperm, Gr. *gumnos*, naked ; *sperma*, seed

Helium, Gr. *helios*, the sun
Hemisphere, Gr. *hemi*, half ; *sphaira*, a sphere
Hepaticæ, Gr. *hepar*, the liver
Homogeneous, Gr. *homos*, same ; *genos*, kind
Horizon, Gr. *horizo*, to bound
Humidity, L. *humidus*, moist
Hydrosphere, Gr. *hudor*, water ; *sphaira*, a sphere
Hygrometer, Gr. *hugros*, wet ; *metron*, measure
Hyperbola, Gr. *huper*, beyond ; *ballo*, to throw

Ichthyosaurus, Gr. *ichthus*, fish ; *saura*, lizard
Igneous, L. *ignis*, fire
Indigenous, L. *indu*, old form of *in ; gigno*, to produce
Inverse, L. *inverto*, to turn round
Isobaric, Gr. *isos*, equal ; *baros*, weight
Isothermal, Gr. *isos*, equal ; *therme*, heat

Lateral, L. *latus*, a side
Latitude, L. *latitudo*, breadth
Lithosphere, Gr. *lithos*, stone ; *sphaira*, a sphere
Littoral, L. *littus*, the shore
Longitude, L. *longitudo*, length

Medium, L. *medius*, middle (anything coming between)
Meridian, L. *meridies*, mid-day
Mesozoic, Gr. *mesos*, middle ; *zoe*, life
Meteorolite, Gr. *meteoron*, suspended beyond ; *lithos*, a stone
Meteorology, Gr. *meteoron*, suspended beyond : *logos*, a discourse
Miocene, Gr. *meion*, less ; *kainos*, recent
Mollusca, L. *mollis*, soft
Monocotyledon, Gr. *monos*, alone ; *kotuledon*, a cup(-shaped leaf)
Monsoon, Malay *musim*, a season
Musci. L. *muscus*, moss

Nebula. L. *nebula*, a little cloud
Nimbus. L. *nimbus*, a rain-cloud
Nitrogen. Gr. *nitron*, nitre; *gennao*, to produce
Node. L. *nodus*, a knot
Normal. L. *norma*, a rule

Oblate. L. *oblatus*, carried forward
Oligocine. Gr. *oligos*, few; *kainos*, recent
Oolite. Gr. *oon*, an egg; *lithos*, a stone
Oosporeæ. Gr. *oon*, an egg; *sporos*, seed
Orbit. L. *orbis*, a ring
Oriental. L. *orior*, to rise; hence the east
Orographical. Gr. *oros*, a mountain; *grapho*, to describe
Oxygen. Gr. *oxus*, acid; *gennao*, to produce
Ozone. Gr. *ozo*, to smell

Palæocrystic. Gr. *palaios*, ancient; *krustallos*, ice
Palæozoic. Gr. *palaios*, ancient; *zoe*, life
Parabola. Gr. *para*, beside; *ballo*, to throw
Parallax. Gr. *para*, beside; *alasso*, to change
Parallel. Gr. *para*, beside; *allelo*, one another
Pelagic. Gr. *pelagos*, the sea
Perihelion. Gr. *peri*, about; *helios*. the sun
Perturbation. L. *per*, thoroughly; *turbo*. to disturb
Phanerogam. Gr. *phaino*, to bring to light; *gamos*. marriage
Phenomenon. Gr. *phainomenon*, an appearance
Philology. Gr. *philos*, loving; *logos*. word (the study of language)
Photosphere. Gr. *phos*, light; *sphaira*, a sphere
Physiography. Gr. *phusis*. nature; *grapho*, to describe
Plane. L. *planus*, even, smooth
Planet. Gr. *planetes*, a wanderer
Pleistocene. Gr. *pleistos*, most; *kainos*, recent
Plesiosaurus. Gr. *plesios*, near to; *saura*, a lizard
Pliocene. Gr. *pleion*, more; *kainos*, recent
Porifera. *porus*, a pore; *fero*, to carry
Potential. L. *potens*, being able
Proteid. Gr. *protos*, first
Protophyta. Gr. *protos*, first; *phuton*. plant
Protoplasm. Gr. *protos*, first; *plasma*, form
Protozoa. Gr. *protos*, first; *zoon*, animal
Pterodactyl. Gr. *pteron*, wing; *daktulos*, finger
Pteropod. Gr. *pteron*, wing; *podes*, feet

Radiation. L. *radio*, to radiate
Radius. L. *radius*, a rod, ray
Rarefaction. L. *rarus*, rare; *facio*, to make
Reflection. L. *re*, back; *flecto*, to bend

Refraction. L. *re*, back ; *frango*, to break
Rotation. L. *roto*, to turn

Satellite L. *satelles*, an attendant
Saurian. Gr. *saura*, a lizard
Secretion. L. *secretus*, from *se*, apart ; *cerno*, to distinguish
Sedimentary. L. *sedimentum*, from *sedeo*, to sit, to settle
Sequence. L. *sequor*, to follow
Sidereal. L. *sidus*, a star
Solstice. L. *sol*, the sun ; *sto*, to stand
Species. L. *species*, an appearance, kind
Spectrum. L. *spectrum*, an image
Spicule. L. *spiculum*. a point
Stalactite. Gr. *stalaktos*, dropping
Stalagmite. Gr. *stalagmos*, a dropping
Stratum (*pl.* strata), **Stratus** } L. *sterno* (*stratum*), to spread out
Subtend. L. *sub*, under ; *tendo*, to stretch
Syncline. Gr. *sun*, together ; *klino*, to lean or incline
Synoptic. Gr. *sun*, with ; *opsis*, a view

Talus. Fr. *talus*, a slope
Tangent. L. *tango*, to touch
Terrigenous. L. *terra*, the earth ; *gigno*, to produce
Thallophyte. Gr. *thallos*, a twig ; *phuton*, a plant
Thermometer. Gr. *therme*, heat ; *metron*. a measure
Transit. L. *trans*. across ; *eo*, to go
Trias. Gr. *trias*, union of three
Trigonometry. Gr. *trigonon*, triangle ; *metron*, a measure
Tropic. Gr. *tropos*, a turning

Universe. L. *unus*, one ; *verto*, to turn

Vacuum. L. *vacuum*, empty
Vermes. L. *vermis*, a worm
Vernal. L. *ver*, spring
Vertebrata. L. *vertebra*, a joint
Vertical. L. *vertex*, the top
Vibration. L. *vibro*, to quiver
Vortex. L. *verto*, a turn or whorl

Zenith. Arabic, *semt-ur-ras*, way of the head
Zero. Arabic, *sifr*, nothing (a starting-point)
Zone. Gr. *zone*, a girdle
Zoology. Gr. *zoon*, an animal ; *logos*. a discourse

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