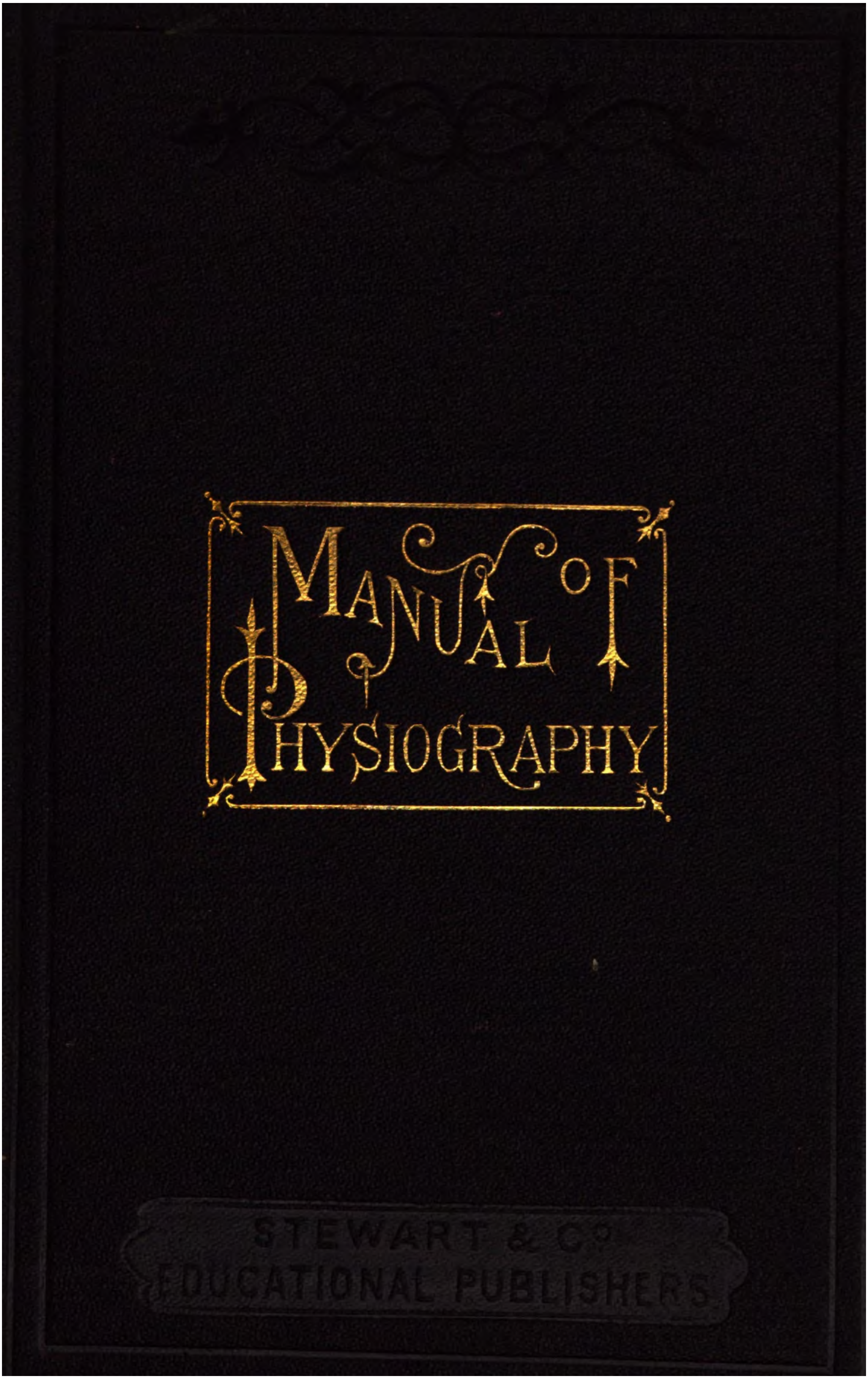

MANUAL OF PHYSIOGRAPHY

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PHYSIOGRAPHY,

ELEMENTARY AND ADVANCED.

PART I.

BY

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PREFACE.

'PHYSIOGRAPHY' has only recently been prescribed as a subject of examination by the Science and Art Department instead of 'Physical Geography.' In the syllabus of the new subject it is stated that candidates for the first stage will still be expected to have a knowledge of ordinary Descriptive and Physical Geography so far as required by the Fifth and Sixth Standards of the New Code, and also of two specific subjects of secular instruction, viz. Physical Geography and the Principles of Mechanics (*vide* Fourth Schedule, New Code). Questions may be set in these subjects as well as in those specified for 'Physiography.' From the syllabus it will be seen that, besides the principal points hitherto classed under 'Physical Geography,' 'Physiography' includes as much of Elementary Physics, Chemistry, Geology, and Astronomy as bears upon and elucidates the subjects selected, and, indeed, might well be called the 'Science of Geography,' using the word in its highest sense, as distinguished from a mere description of the surface of the globe and a few exterior points. This, although absolutely necessary and most useful towards further research, is but a simple record of facts, serving nearly the same purpose as dates in history. It is, of course, necessary that we should know when such and such a thing happened, yet a date-book gives but a very faint idea, if any at all, of the *history* of a country. So with Geography as a Science. We must not, as M. Guyot eloquently remarks, 'coldly anatomize the globe by merely taking cognizance of the arrangement of the various parts which compose it. We must endeavour to understand those incessant mutual actions of the different portions of physical nature upon each other . . . in a word, we must study the reciprocal actions of all these forces, the perpetual play of which constitutes what may be termed the "Life of the Globe."'

J. W.

The Publishers of this work, Messrs. W. Stewart & Co., London, have issued admirable illustrated text-books for the above-mentioned specified subjects, which teachers would do well to put in the hands of their junior scholars.

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PART I.

FIRST STAGE, OR ELEMENTARY COURSE.

PHYSIOGRAPHY.

CHAPTER I.

INTRODUCTORY—ON MATTER.

1. **Matter.**—What is matter? We may define matter to be that which occupies space, which space cannot be occupied by more than one form of matter at the same time. From this definition we see that matter possesses certain properties by which only its existence is revealed to us—or, in other words, matter is known to us only by its properties. Two of these are included in the definition we have given—viz., *extension*, or the occupation of space by matter of whatever form; and *impenetrability*, or the impossibility of more than one form of matter occupying the same space at the same time. These two properties are essential to the existence of all bodies; other properties, though not essential to the existence of matter, yet serve to distinguish the various forms in which it is presented to us.

2. **Particles, Molecules, Atoms.**—The smallest portions of matter that we can possibly get by artificial means are termed *particles*. Each particle consists of several smaller portions called *molecules*, each of which again is made up of still smaller *atoms*, which are the ultimate constituents of all forms of matter. Atoms are so exceedingly minute that they cannot be divided physically; they are 'retained side by side without touching each other, being separated by distances which are great in comparison with their supposed dimensions.' How far the divisibility of matter is carried out may be seen from the following experiment:—Let a grain of iron be dissolved in an acid, and mixed with twenty million grains by weight of water; then let a grain of the solution be concentrated by evaporation and chemically tested: the presence of the iron will be detected. This proves that the grain of iron has divided itself into at least twenty million parts. A piece of musk has been known to perfume a large room for twenty years, yet losing only one grain in weight. Into how many millions of parts that grain must have been subdivided, so as to perfume the room uninterruptedly for twenty years! Sir W. Thomson gives the following illustration of the size of molecules:—'Imagine a drop of rain or a glass sphere the size of a pea magnified to the size of the earth, the molecules in it being increased in the same proportion. The structure of the mass would then be coarser than that of a heap of fine shot, but probably not so coarse as that of a heap of cricket balls.'

3. **The Three States of Matter.**—The various forms in which matter exists depend upon and are the result of the relative arrangement of its molecules.

Each atom (and consequently each molecule, which is but an aggregate of atoms) is supposed to be surrounded with a film or atmosphere of heat. Heat, being a repulsive force, tends to separate the atoms and molecules from each other. Against this there is the inherent attractive power of gravity, which tends to bring the molecules close together; so that the arrangement of the molecules of all bodies depends upon the relation between the attractions and repulsions taking place between them. If the attractive power predominates, the molecules are firmly fixed in certain positions, which cannot be changed without the exertion of force of some kind. The body therefore is *solid.* If the two forces are equal or nearly so, their effect is neutralized, and the molecules become indifferent to each other; consequently they yield to the slightest pressure, and are held together in masses simply by the vessel which contains them, or in smaller portions by the force of cohesion. The body, therefore, is *liquid.* But if repulsion overpowers attraction, the molecules are separated from each other almost indefinitely. The body, therefore, is *gaseous.* Now the mutual relation of these molecular forces, as they are called, varies with temperature. Nearly all the simpler bodies, as well as many compounds, can be made to pass through all the three states by raising or lowering their temperature. For instance, water at the ordinary temperature is liquid; but if the temperature be sufficiently lowered, it solidifies as ice, which can be reconverted into a liquid by the application of heat. Water, again, by heating ultimately assumes the gaseous form as steam. The latter process is always attended with a large increase in the bulk or volume; thus, one cubic inch of water makes 1700 cubic inches of steam.

4. **General Properties of Matter.**—The essential properties, *extension* and *impenetrability*, have been already noticed (art. 1). These properties, together with another termed *attraction*, apply to atoms as well as to large masses of matter. Other properties are common to all bodies, though not essential to their existence. These do not apply to atoms, but only to aggregates of atoms or masses of matter. The principal are *divisibility*, or the division of a body into parts; *porosity*, or the existence of openings or pores between the particles of a body (these are either physical or sensible, the former denoting the invisible intermolecular spaces, the latter, actual visible cavities); *compressibility*, or decrease in volume by pressure, which follows from porosity; *elasticity*, or resumption of original shape after the disturbing cause is withdrawn (developed by bending, twisting, pressing, or pulling, limited in solids, unlimited in liquids and gases); *mobility*, or change of position (*motion* and *rest* are generally used in a relative sense, there being, strictly speaking, no such thing as absolute rest or motion); *inertia*, or the total absence of power in matter of itself to change its condition of rest or motion.

5. **Specific Properties of Matter.**—The following belong to a limited number of bodies in certain states only. Of these some are peculiar to solids, such as *tenacity*, or the resistance offered by bodies to traction, the degree of tenacity being determined by the weight necessary to break them; *ductility* and *malleability*, or the change of form by traction or hammering (platinum is the most ductile: platinum wire can be made of only ·0003 of an

inch in diameter; gold is the most malleable, and can be beaten out into leaves $\frac{1}{300,000}$th of an inch in thickness); *hardness*, or the resistance to wear, used in a relative sense (diamond is the hardest body; alloys are harder than the pure metals). Properties peculiar to liquids are *capillarity*, a variety of cohesion exemplified in sponges, etc.; *diffusion*, or the gradual intermixture of two liquids, either through a thin intervening partition or otherwise; *imbibition*, or the 'sucking' up of a liquid into the pores of a solid. Similar properties are also possessed by gases, termed *effusion*, or the passage of gases into a vacuum through minute openings, or the intermixing of two gases through an intervening porous diaphragm. The peculiar property of gases, and which distinguishes them from solids and liquids, is their almost unlimited expansive power, or *expansion*.

6. **Attraction.**—This is one of the most important properties of matter, and presents itself to us in a threefold aspect, the same in principle, but differing in degree, viz. as *gravitation*, *cohesion*, and *chemical affinity*. These we shall notice at length in the next chapter.

7. **Concluding Remarks on Matter.**—Matter is indestructible. We cannot by any means destroy matter. We may change its form and properties, but we cannot annihilate the least portion of it. This can be proved by many simple experiments. For instance, when phosphorus burns, the oxygen of the air unites with the phosphorus, producing dense white fumes. Now, if we weigh these fumes, we find that they are exactly equal in weight to the phosphorus and oxygen burnt, showing that combustion has not been attended with the least loss in weight. Nor, on the other hand, is there any

gain of matter, and at this moment there is not an atom in the whole universe but existed in some form or other thousands of years ago. In all chemical and physical changes there is no creation of new matter, but simply new combinations of existing matter.

CHAPTER II.

ON THE PARTS PLAYED BY GRAVITATION, COHESION, AND CHEMICAL AFFINITY IN PRODUCING CHEMICAL AND PHYSICAL DIFFERENCES IN MATTER.

8. **Physical Forces.**—Whatever acts upon matter so as to produce physical changes in its properties or state, is termed a physical agent or natural force. Thus, in converting ice into water, heat is the agent employed. Among the principal forces of nature are *attraction* in its threefold aspect (as gravitation, cohesion, and chemical affinity), *heat*, *light*, *magnetism*, and *electricity*.

9. **Attraction** (L. *attraho*, to draw) is the general term for that power by which particles of matter are mutually drawn towards each other, in the same manner as a magnet attracts iron, with this difference, that magnetic attraction only takes place between the magnet and the iron, while the former is exerted by all bodies indiscriminately. When attraction takes place between large masses of matter at visible distances, it is called *attraction of gravitation;* when it operates between molecules of the same kind at inappreciable distances only, it is termed *attraction of cohesion;* when it is exerted between molecules not of the same kind, it is called *chemical attraction* or *affinity*. A further variety of attraction between the molecules of

different bodies, when placed in contact, is termed *adhesion*. *Capillary attraction* is also an example of cohesive attraction.

10. **Gravitation or Gravity.**—Gravitation is that form of attraction which is exerted between large masses at visible distances, and is usually treated of under the two heads, *terrestrial* and *universal gravity*. *Terrestrial gravity* is that power by which the earth attracts bodies and causes them to gravitate towards itself. This is simply a particular case of *universal gravitation*, by which we understand the attraction manifested not only between minute particles of matter at small distances, but also between the largest masses at great distances.

11. **Laws of Gravitation.**—These laws, first determined by Sir Isaac Newton, relate first to the *mass* of bodies, and secondly to their *distance*.

First, *the force of gravitation between two bodies is in a direct ratio to their mass*—that is, if A be 100 times greater than B, A's attracting force will be 100 times greater than B's; for since every particle of matter is endowed with the power of attraction, therefore the greater the number of particles, or, in other words, the greater the mass of a body, the greater will be its attracting power. All bodies attract each other, but the attraction of the larger body overpowers that of the smaller. Thus the sun, which is 500 times greater than all the planets put together, exerts such an attractive force that they would all be soon drawn into it were it not for the counteracting influence of the *centrifugal force*.

Secondly, *the force of attraction is in an inverse ratio to the square of the distance of one body from another*—that is, it diminishes with the square of the distance. That is, supposing a body A to be at a certain distance from another body B, at twice that distance A's attracting force on B would be reduced to one-fourth, at three times that distance to one-ninth, etc. Thus the sun, acting upon two planets E, F, one of which (E) is twice as far as the other (F), attracts F not twice, but four times as much as E.

12. **Centre of Gravity.**—In all bodies there is a certain point into which all their weight or gravity seems to be condensed, as it were. This point is called the *centre of gravity*. In spherical bodies it is at their geometrical centre, in other bodies it can be easily found by suspending them freely in two different positions and marking the direction of the suspending line each time. The point where these lines intersect is the centre of gravity.

13. **Use of Gravity.**—The part played by gravitation in producing physical differences in matter is evident. By cohesion, molecules of the same kind mutually attract each other, forming visible bodies. By the force of gravitation all the various bodies of which the earth is composed are drawn with equal force from all sides towards the centre. The result of this equality of force is shown in the globular form of the earth. Were it not for *terrestrial gravity*, there would be no weight. Consequently bodies would not necessarily fall to the earth; the stones and debris loosened from the mountain-sides would not roll down to the intervening valleys; rivers would not rush impetuously to find their lowest level; the various materials of which the earth is composed would no longer be bound together round the earth's centre, but would separate from each other indefinitely, utterly indifferent to one another, and consequently utterly

incapable of further union. Again, were it not for *universal gravitation*, the earth, supposing it intact, would not be attracted by and to the sun, and, obeying the only force (the centrifugal force) acting upon it, would fly off in a straight line into space. The sun itself, most probably controlled by the stronger attraction of a vastly greater sun, the instant this force were withdrawn, would leave its apparent rest and rush off into space—that is, supposing it intact. But the very materials of which the sun and other heavenly bodies consist are kept together by this force, so that, if it were wanting, these would lose cohesion, and the bodies themselves would fall to pieces. In fact, the force of gravitation plays such an immensely important part in the economy of nature, that its suspension even for a moment would be attended with the total destruction of all existing *forms* of matter.

14. **Cohesion.**—Cohesion is that species of attraction which is exerted between molecules of the same kind. It is only exerted at very small distances, and differs in intensity in different bodies. In solids it is strong, in liquids much less so, in gases slight, if at all. Heat decreases it; therefore if heat be applied to a body, its molecular state is changed. Thus ice may be converted first into water and then into steam, the degree of cohesion growing less and less, until at last it seems to disappear altogether. By abstracting the heat from vapour, these changes are reversed, and the liquid and solid states restored. Cohesion is also overcome by chemical attraction, or, in other words, cohesive attraction between the same kinds of molecules is neutralized by chemical attraction between different kinds of molecules. Thus, if a lump of sugar be dropped into water, the chemical attrac-

tion between the molecules of the sugar and those of the water overcomes the cohesion of the sugar, which is consequently dissolved. On withdrawing these counteracting forces, cohesion is resumed between the separated molecules, and the body reverts to its original molecular state, though not in the same form, which depends on the suddenness or slowness of the reversing process. When cohesion is allowed to re-exert itself suddenly, the resulting mass takes no definite form; but when the process is slow, the various particles assume regular crystalline forms. This process is termed *crystallization*. Thus, if sulphuric acid be dropped into a solution of nitrate of barytes, sulphate of barytes is produced in the state of a white powder. On the other hand, water, if cooled gradually, is converted into prismatic crystalline ice.

15. **Use of Cohesion.**—The difference between the parts played by these two forms of the same general principle, viz. gravity and cohesion, is this: the former is exerted between aggregates of molecules or masses of matter, of whatever kind, at distances however great, while the latter binds molecules of the same kind, and is only exerted at inappreciable distances. The use, therefore, of cohesion is to preserve unchanged the molecular state in which bodies exist or are made to assume. Thus ice, so long as the repellent power of heat is not present, is preserved in its solid state by the cohesion of its particles. When it is converted into water, a less intense cohesion preserves it in its liquid state. No cohesion whatever exists between gaseous molecules. The degree of cohesion, then, determines the state of a body. The globular forms of small masses of liquids are also due to cohesion. In larger masses cohesion is overcome by gravitation,

the masses of each ingredient is destroyed by reducing the whole to powder, the application of heat is immediately followed by an explosion, thus showing that the chemical action necessary to produce the ignition and explosion of the mass only exerted itself when the particles of the various bodies were brought close together. Heat also modifies affinity. Thus no combination takes place between sulphur and oxygen until the former is heated, upon which the two unite to form sulphuric acid.

18. **Use of Chemical Affinity.**—This will have been already inferred from the preceding remarks. We have shown that chemical affinity is that power by which two or more substances act upon each other in such a manner as to produce another substance, differing entirely from the original substances. Were it not for chemical affinity, then no compound forms of matter could exist. All bodies would be simple. Oxygen and hydrogen would not then combine to form water. Combustion would not take place, as oxygen would not unite with any other element. Everything, animate and inanimate, would be resolved into its ultimate elements. The earth would not be habitable ; our own bodies would be instantly decomposed ; the sun's light would be extinguished, and its heat quenched ; in short, the whole universe would be physically dead.

CHAPTER III.

ON THE VARIOUS CONDITIONS OF MATTER AS REGARDS ENERGY, EMBRACING HEATED STATES AND ELECTRIC AND MAGNETIC STATES.

19. **Conditions of Matter.**—The three *states* of matter are the solid, liquid, and gaseous. But a solid, for instance, is not always in the same *condition*, although no change of state takes place. Thus the conversion of a solid into a liquid implies a change of state, but the conversion of rest into motion is simply a change of *condition*. A cannon ball lying motionless on the ground and when discharged with great velocity from a cannon, is one and the same substance, and in both cases in the same *state* (solid); so that the difference between the ball in the two cases is one of *condition* only—that is, in the first case it is in that condition termed rest, in the second in that termed motion. Again, hot water is very different from cold water; but the difference is not in state—for the water in both cases preserves its liquid form—but in condition. Again, the difference between two tubes of the same kind of glass, one of which has been well rubbed with woollen cloth or silk, and the other has not been so treated, is shown by the fact that the former is capable of attracting light bodies to it, while the latter has no such power. The difference,

then, here is really one of condition, expressed by saying that the rubbed tube is electrified, the other not. There is apparently a change of properties in the former case, but strictly speaking no change in the original properties of the glass has taken place; for the glass still keeps its solid state, and in other respects is precisely similar to the second tube, so that the electricity must be an additional property developed by rubbing. Again, the difference between two pieces of iron or steel, one of which has been magnetized, is shown in a similar manner by its attraction or repulsion. The magnetic power conferred upon the first piece does not change its original properties, but is simply an additional property artificially developed in it. The rapid vibratory motion of the molecules of the luminiferous ether is another form of energy called *light;* and a similar motion of the particles of bodies transmitted to the ear, through the medium of the air, constitutes what is called *sound.* In the two latter cases the undulations to which the ether and the air are subject do not change any of their properties.

20. **Work, Energy.**—The difference in condition between a body at rest and a body in motion is expressed by saying that in the former case it is inert, in the latter case that it possesses *energy,* which we may define as the capacity for doing *work.* Thus stagnant water is inert, but a running stream is full of energy and capable of doing a considerable amount of work. By the term work, then, we mean that exertion of force necessary to cause bodies naturally inert to assume a state of motion, or to induce and maintain a state of motion in opposition to other forces: the latter may or may not be accompanied by a change of position.

Thus a man rowing a boat exerts force to produce motion, which is perceptible by the change of position assumed by the boat. But suppose he was rowing say against the current, and suppose that the force exerted by him to propel the boat to be equal to that of the current, the one would neutralize the other, and no change of position would take place, although as much or more *energy* was expended as in the former case. Therefore when a force produces motion, or when it maintains that motion unchanged against resistance, or when it prevents any change induced by other forces, such a force is said to do work, termed in the first case *work of acceleration*, in the latter *work against resistance*. The 'unit of work' is the quantity of work done in lifting one pound a height of one foot, and is known as a foot-pound, so that if we multiply the number of pounds by the number of feet, the product will be the work done. In the case of moving bodies, a double velocity always gives, not twice, as might be thought, but four times the amount of work. Thus if a cannon ball moving with a certain velocity pierces three planks, the same ball with twice that velocity would pierce through nine planks of the same thickness. In conclusion, then, anything capable of doing work is said to possess *energy*, and the quantity of energy is measured by the amount of work done. Energy in a limited sense simply refers to the forces which produce states of rest in moving bodies or motion in inert bodies. But in its wider application it includes the *capacity for producing physical change of any kind*, and these may be classed under six heads, viz. motion, sound, light, heat, magnetism, and electricity. We shall therefore briefly consider these points in order.

21. **Motion.**—By motion we mean simply a change of position. When a body in motion is compared with other bodies at rest, it is said to be in *absolute* motion; when it is compared with other bodies also in motion, it is said to be *relatively* in motion. A body at rest cannot put *itself* in motion, and similarly a body in motion cannot *of itself* stop moving. Anything that acts upon a body at rest so as to cause it to move, or upon a body in motion so as to cause it to stop, is called *force*. Gravity, friction, electricity, etc. are *forces*. All changes from rest to motion, and *vice versa*, are due to the action of one or more of these forces. Now, all bodies keep their state of absolute rest or uniform motion in a straight line, unless they are compelled to change that state by other forces acting on them. Thus a cannon ball cannot move of itself; but if placed in a cannon and the charge exploded, it is made to move with great velocity. Were it not for the resistance of the air and the increasing action of gravity, it would proceed in the direction in which it was projected to an indefinite distance. Again, when a body is put in motion, it moves with a velocity proportional to and in the same direction as the force applied. If the velocity or rate of movement is constant, the motion is said to be *uniform;* if decreasing, to be *retarded;* if increasing, to be *accelerated*. Again, every action is always opposed by an equal reaction. Thus when a ball is thrown against the wall, it rebounds, owing to the reaction of the wall. When two or more forces act simultaneously on the same body in the same distance, the *impetus* given to the body will be equal to the *sum* of these forces. But supposing a body to be acted upon by two forces acting in opposite directions, if the two are

equal and balance each other, the body will not be moved; but if they are unequal, the impetus given will be equal to the *difference* between the two, and the motion will be in the direction of the stronger force. But if two forces act neither in the same nor in the opposite directions, the body will move in a line between the two. Thus if the two forces are at angle of 90°, the body acted upon will move in the diagonal of a square or rectangle; therefore, whatever the angle between the two forces, the body acted upon will move in the diagonal of a parallelogram. Further, if a body be acted upon by two equal or nearly equal forces, by one of which it would be projected forward in a straight line, while by the other it would be drawn to a fixed centre, the body will describe a circle. The former or projected force is called the *centrifugal force*, the latter the *centripetal force*. To the joint action of these two forces is due the curvilineal motions of the planets round the sun. The earth,

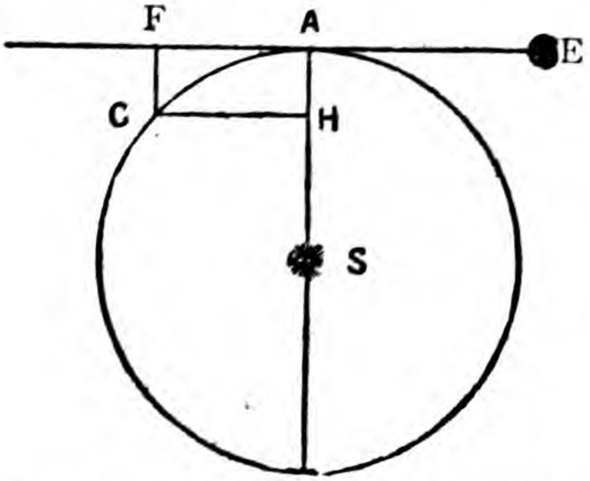


Fig. 1. Illustrating the curvilineal motion of the earth E round the sun S. By the centrifugal force E is impelled to F, by the centripetal to H,—both acting simultaneously, E moves in the diagonal AG, and so on, until E again arrives at A.

for instance, is always drawn towards the sun by the centripetal force, while the centrifugal force impels it to fly off at a tangent. The consequence is, that the earth revolves in a circular or nearly circular orbit. But if these forces are unequal, other forms of compound motion are produced. Thus if a stone be thrown in a horizontal direction, the uniform motion caused by the projectile force is finally overcome by the *accelerated* motion caused by the force of gravity, and the stone is brought to the ground after describing a parabolic curve.

22. **Sound.** — The peculiar sensation we call *sound* is caused by the vibratory motion of bodies transmitted through the air, or some other elastic medium, to the ear. A body which produces sound is called a *sonorous* body. That an elastic medium is absolutely necessary for the transmission of sound is proved by the fact that sound cannot be propagated in vacuo. The passage of a wave of sound through the air is performed not by any actual change in the position of the particles first set vibrating, but each particle oscillates to and fro, imparting motion to other particles round it. These, again, give motion to other particles, and in this manner the sound wave travels from the sonorous body to the ear. Several causes modify the *intensity* or loudness of sound, such as the *distance* of the sonorous body from the ear (which is inversely as the square of the distance, thus for double the distance the intensity is only one-fourth). Another cause is the *density* of the air (this may be shown by placing a small bell moved by clockwork in the receiver of an air-pump; as the air is gradually exhausted or diminished in density, the sound gets gradually feebler, and at last entirely ceases). Thus if a small cannon be fired on the top of a high moun-

tain, the sound is much weaker than when it is discharged in the valley below. It must be remembered that the *density* of the medium affects the *intensity* only, and not the *velocity* of sound. Sound is also strengthened when a sonorous body is near to the vibrating body; thus sounding boxes are used in all stringed instruments. By the *velocity* of sound we mean the rate at which the sound wave travels, and this has been experimentally determined to be 1093 feet, or 333 metres per second at zero. Velocity of sound increases with the temperature at the rate of about 2 feet per second for every degree centigrade. The difference in the transmissive power of solids, liquids, and gases will be seen from the fact that while in air at zero the velocity is 1093 feet per second, in hydrogen it is 4163 feet, in fresh water at 13° C. 4714 feet, at 30° 5013 feet, in oak 12,622 feet, in iron 16,822 feet. The latter may be proved by standing at one end of a long iron railing, and getting some one else to strike the rail at the other end. For every blow *two* sounds will be heard, the first through the iron and the second through the air, thus proving that the sound travelled much more rapidly through the iron than through the air. Sound is *reflected* when the sound wave strikes

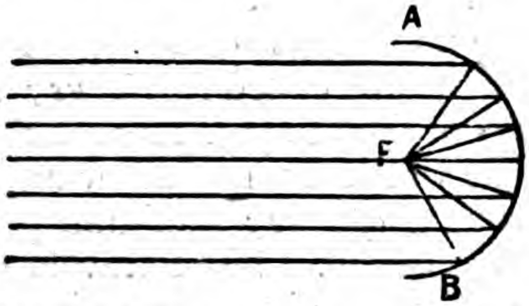


Fig. 2. Showing the reflection of sound from a concave surface AB to a focus F.

against something in its course, and is, as it were, thrown back on itself. An *echo* is a familiar instance of the reflection of sound. When the vibrations of a sonorous body are perfectly regular and uniform and rapid enough, *musical sounds* are produced; and the greater the number of vibrations in a given time, the higher the *pitch* of the note, and *vice versa*. The number of vibrations can be exactly determined by several apparatus, such as Savart's toothed wheel, the Syren, etc.; 16 vibrations per second produce the lowest, and 32,000 the highest sound perceptible by the human ear.

23. **Light.**—What light is, whether it is a material substance, or whether it is simply a vibratory motion of the particles of luminous bodies, is still doubtful, although modern scientists incline to the latter view. According to the first theory, light is propagated by the actual translation of material particles given out from luminous bodies. A portion of these enter the eye and excite the sensation of vision. According to the second or undulatory theory, light is propagated in the same manner as sound by undulations or waves, but with this difference, that sound waves are undulations of *air*, and light waves undulations of *ether*. Those bodies which emit light are called *luminous;* those which allow the rays of light to pass through readily, *transparent;* those which do not allow any of the rays to pass through, *opaque;* semi-transparent bodies are called *translucent*. Light travels with such a velocity as to be transmitted almost instantaneously. Its velocity was first determined in 1675 by Romer, a Danish astronomer, from observations on the eclipses of Jupiter's first satellite, and it was proved to be nearly 200,000 miles per second, so that the

light from the sun reaches the earth in about 7½ minutes; a cannon ball at its greatest velocity would take more than seventeen years to traverse the same distance. The *intensity* of light increases or diminishes inversely as the square of the distance between the luminous and the illuminated body. When rays of light fall on any surface, they are either *reflected*, *absorbed*, or *transmitted*. If the ray falls at right angles, it is reflected back at right angles in the same direction in which it came. The same is the case whatever the angle,—that is, the ray will be thrown back in a line making the same angle,—so that the *angle of reflection is equal to the angle of incidence*. Thus if a man stands right in front of a mirror, he sees his image directly before him; but if he stands a little to the side, he cannot see it, although a second person standing on the other side would see it distinctly. Light travels in straight lines so long as it passes through a uniform medium; but when it passes from one transparent body to another of different density, it is more or less bent from its course towards the perpendicular: this is termed the *refraction* of light. A familiar instance of the refraction of light is the apparent

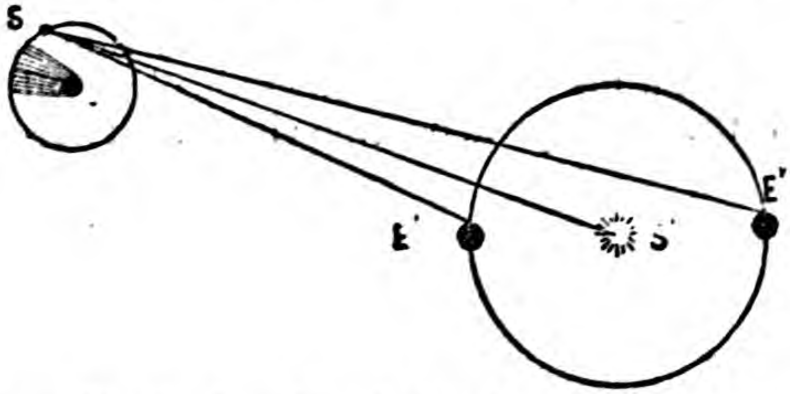


Fig. 3. Showing how the velocity of light was determined by Romer. S^1, *sun;* S^2 *satellite:* J, *Jupiter;* E^1, E^2, the *earth.*

shallowness of really deep pools or lakes, the bottom being as it were lifted up: the part of an oar under the water seems bent. Again, if a shilling be placed at the bottom of a basin in such a position that it will be just hidden by the side of the basin, and if the basin now be gradually filled with water, the shilling will become visible. Thus, also, we see the sun when it is really several degrees below the horizon; to this cause is also due the phenomena of twilight, mirage, etc. Light is of a compound nature. If a ray of light be made to pass through a small aperture into a darkened room, and a prism be placed in its path, the ray will be decomposed into seven coloured bands (called a spectrum) in the following order:—red, orange, yellow, green, blue, indigo, and violet. The colour of objects, then, depends upon the absorption of some of the coloured rays, and the reflection of the rest to the eye of the observer. When all the rays are reflected, the object appears white; when all are absorbed, it is black; when the red rays are chiefly reflected and the rest absorbed, the object is red, and so on of every other colour. The rainbow

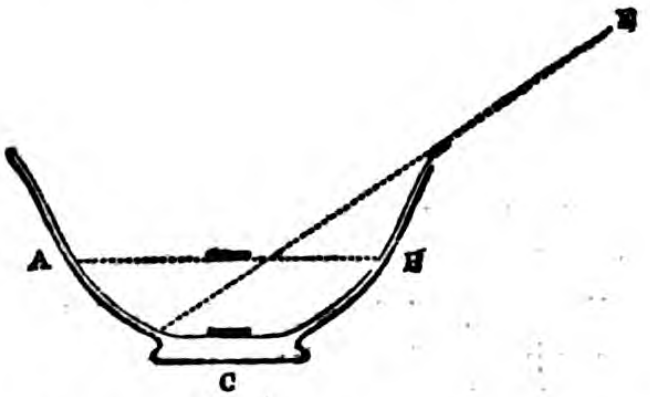


Fig. 4. Illustrating the refraction of light.

is a familiar instance of the decomposition of light. Light also has chemical power. Thus chlorine and hydrogen combine readily only under the influence of light, and chloride of silver turns nearly black when exposed to the sunshine. *Photography* is based upon the chemical power of light. Light is also essential to the healthy growth of animals and vegetables. The weakly constitutions and pallid faces of those who pass a great deal of time in ill-lighted rooms is an instance of the former; the 'blanching' of celery, by excluding the light, of the latter. To the chemical power of light is due the germination of the seed; to the luminous rays, the subsequent growth of the plant; and to the heat rays, the processes of flowering and ripening.

24. **Heat.**—The term heat is generally used to express the sensation of warmth. The principal sources of heat are the sun, electricity, and chemical and mechanical action. The solar rays convey both light and heat, and if a number of them be collected in a burning glass, a piece of paper or linen placed in the focus will immediately take fire and burn. The most intense heat is developed by electrical action. This is proved by the fusion of the hardest substances. Chemical action also produces heat. Thus if water be poured on well-burnt lime, the lime in a few minutes bursts into small pieces with a crackling noise and becomes very hot, as shown by the conversion of a part of the water into steam. Animal heat, or the heat of animal bodies, is developed and maintained by the combination of the oxygen of the air and the carbon of the food. Mechanical action, such as friction, percussion, etc., produces heat. Thus savages procure fire by rubbing together two pieces

of dry, hard wood; or if a piece of metal be struck with a hammer, heat is immediately produced. By the *temperature* of a body is meant the degree of heat it possesses; and as bodies are variously heated, some being hot, others warm, others cold, there is a constant interchange of heat going on. Thus when two bodies of unequal temperature are in contact, an interchange of heat immediately takes place; but that from the warmer to the colder body being of course greater than that from the colder to the warmer, the result is that the latter is gradually cooled and the former gradually warmed, until they are both of the same temperature, or in *equilibrium*, which, although the interchange of heat still goes on, is maintained the same, since each body receives as much as it parts with. This is called *conduction* of heat, and goes on incessantly between all bodies in contact. Generally speaking, the denser the body, the greater its power of conducting heat. Clothing is made of imperfectly conducting substances, so as to prevent the escape ot heat *from* the body. Besides communicating heat by contact, heat is also communicated from hot to cold bodies by *radiation*, *e.g.* the sun and the earth. All bodies radiate heat, but the amount radiated depends not so much on the nature of the body as upon the nature of its surface. Brightly-polished surfaces are usually bad radiators, dark, dull surfaces generally good radiators. Heat, by overcoming the force of cohesion, changes the state of bodies. Thus ice melts, and water is changed into steam or vapour, when heat is applied. Heat, then, liquefies solids, and vaporizes liquids. Again, an iron rod when cold cannot be bent without using great force; but if the same rod be heated to redness, it bends easily, thus showing that the cohesive force between the particles has been weakened. Chemical action also is variously affected by heat. Thus if masses of ice and quicklime be placed in contact, no chemical action takes place. When, however, the ice is liquefied, the quicklime rapidly absorbs the water; but if the compound thus formed be subjected to an intense heat, it is again resolved into quicklime and water. In the first instance heat favoured chemical action by weakening the force of cohesion, in the second instance the chemical union of the lime and water was dissolved by it. Heat weakens the force of cohesion or chemical attraction by increasing the repulsive force of the particles of which a body consists, and thus increasing their distance from each other. All bodies, then, expand when heated. The degree of expansion differs in different bodies; thus lead expands far more than iron, and melts much more rapidly. In solids the degree of expansion is slight, in liquids much greater, in gases almost if not altogether unlimited. The expansion of solids may be shown by taking a metallic ball which just fits a certain ring—that is, will just pass through it. Now if the ball be heated, it will not pass through the ring, thus proving an increase in the size of the ball. Thus also on railroads small spaces are left between the ends of the rails. The expansion of liquids may be shown by filling a flask with spirits of wine to the lower part of the neck; on heat being applied, the spirits will be expanded, and will rise up in the neck for some distance. The expansion of gases may be shown by filling a bladder two-thirds full of air and warming it before the fire: the bladder will swell out to its full size.

25. **Magnetism.**—Magnetism is generally defined

as the power which certain substances have to attract iron. Such bodies are called magnets, and are either ***natural***, as magnetic oxide of iron or loadstone, or ***artificial***, as bar or horse-shoe or *electro* magnets. The attractive power of the magnet is greater at the ends, and least (or none at all) in the middle. The ends are called ***poles;*** the middle line of no attraction is termed the ***neutral line.*** This may be shown by dipping a magnet in iron filings: the filings will adhere in tufts at both ends, but gradually decrease towards the middle, which is bare. Although the two poles of a magnet have each equal attractive power over iron, there is a great dissimilarity in their action. If two good horse-shoe magnets be brought together end to end (the marked end of the one being opposite the unmarked end of the other), a strong attraction takes place. But if the two marked, and consequently the two unmarked ends, be presented to each other, no attraction takes place. The marked end, then, of one will not attract the marked end of the other, but only the unmarked. The marked end is called the ***north pole***, and the unmarked end

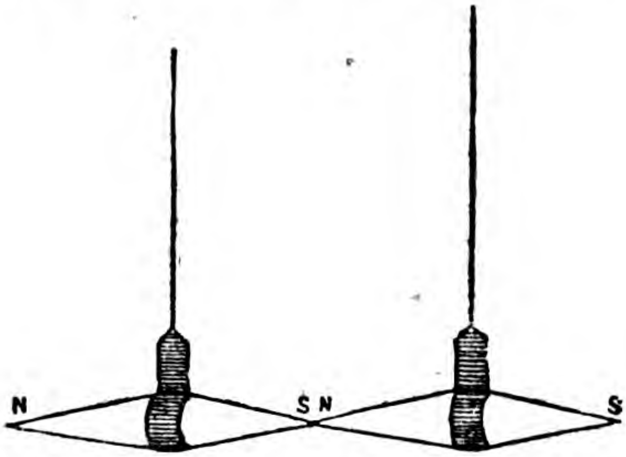


Fig. 5. Illustrating magnetic attraction and repulsion.

the *south pole* of the magnet. Again, if a small magnetic needle be freely suspended by a fine thread, and the north pole of another needle be brought near its south pole, attraction takes place. But if the north pole of the second needle be presented to the north pole of the first, repulsion takes place. Hence *poles of the same name repel, and poles of contrary names attract one another.* One end of a magnet, then, has north polar magnetism, and the other end has south polar magnetism, and exactly between the two ends is the neutral line. Now, if we divide the magnet into two equal parts in the neutral line, we might think that north polar magnetism only would be found in one piece, and south polar magnetism only in the other piece, and that one end of each of the pieces coinciding with the neutral line of the original magnet would have no magnetic power whatever. Is this the case? No. Both pieces will be found to have a north and south pole and a central neutral line; so that it does not matter how far we divide and subdivide a magnet, for each piece will be a perfect magnet. The earth also acts like a huge magnet. A small magnetized needle, freely suspended horizontally, takes a fixed north and south position. Artificial magnets are either bar or horse-shoe or electro magnets. Powerful magnets of each kind are made up of bundles of bars or 'shoes,' each of them a perfect magnet. Now if a bar of soft iron be suspended from the end of a magnet, it is temporarily magnetized by *induction.* On removing it, this temporary magnetism immediately disappears. If, however, a piece of steel be so treated, it does not acquire magnetic properties so readily; nor does it, when it is once acquired, part with it so readily as the soft iron did.

The steel then resisted first the assumption and then the withdrawal of the magnetism. This resistance to acquire or part with magnetism is termed *coercive force.* Steel bars are artificially magnetized in several ways,—by single touch, double touch, or by the galvanic current. Common magnets are magnetized by the two first methods; but those magnetized by the galvanic current, called electro magnets, are the most powerful. Magnetism is sensibly affected by heat, decreasing when the temperature rises, and *vice versa.* That all bodies are more or less susceptible to the influence of magnetism, was first determined in 1845 by Faraday, and the experiments which he made in this direction are many and very interesting. He classed all substances as *paramagnetic, e.g.* iron, paper, etc.; or *diamagnetic, e.g.* bismuth, gold, leather, etc.

26. **Electricity.**—The term electricity is derived from the Greek *electron,* signifying amber, in which substance electrical effects were first observed. By some it is supposed to be a subtle, imponderable fluid (identical with lightning), by others a peculiar property of matter. Whatever its nature, its action is sufficiently evident. Thus if we rub a tube of glass or a piece of sealing-wax with dry silk or woollen cloth, we find that small bits of paper or any other light bodies are immediately attracted. This attraction (called *electrical attraction*) is due to the electricity developed on the surface of the glass or wax by rubbing or friction, and is therefore called *frictional electricity.* Now although both the rubbed glass and the rubbed wax manifest their electrical properties in the same way,—that is, by attracting light bodies,—the electricity of the glass differs in kind from that of the wax. This

may be shown by suspending a small paper loop by a fine thread, and placing a stick of rubbed sealing-wax in the loop so as to lie horizontally or level. Now if another stick of rubbed wax be presented to the first, *repulsion* takes place. But if instead of the wax a small glass tube well rubbed with silk be placed in the loop, and another tube of glass similarly rubbed be brought near the first,

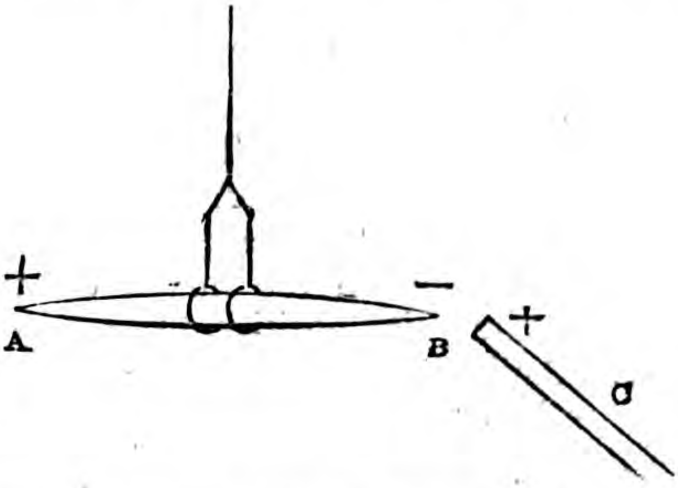


Fig. 6. Illustrating electric attraction and repulsion.

repulsion again takes place. But if the rubbed wax be placed in the loop, and the rubbed glass be brought near it, *attraction* takes place, as also when the rubbed wax is presented to the rubbed glass; so that the electricity of the wax *repels* that developed on another piece of wax, but *attracts* that of the glass, and *vice versa.* There is, then, a manifest difference between the electricity in each case. That of the glass is called *vitreous*, and that of the wax *resinous;* or the former is generally called *positive*, and the latter *negative* (+and−). Similar effects are observed in all vitreous and resinous substances, so that *electricities of the same name repel one another, and electricities of contrary* *names attract one another.* Now the electricity developed by rubbing the glass or the wax is held fast as it were on the surfaces of both; but if a metallic rod be similarly rubbed, the electricity developed in it immediately escapes. The latter, then, *conducts* the electricity away quickly; the former does not permit it to escape so readily. Hence the terms *conductors* and *non-conductors.* Electricity exists in all bodies, but in a free or mixed state; and therefore the one kind neutralizes the other, so that no electrical effects are manifested. Friction, etc., separates the two kinds which are then in a condition to act. Thus if the positive end of an electrified body A be presented to an unelectrified body B, the positive electricity of A acts by *induction* on the mixed electricity of B, so as to separate its positive from its negative electricity. And since the positive end of A is nearest to or in contact with B, the positive electricity of B is *repelled* and driven to the end farthest from A, while the negative electricity of B is *attracted* to the end near A. If the negative end of A had been presented to B, the positive electricity of B would then be attracted to the point nearest A, and so on. When two bodies, one positively and the other negatively electrified, are brought near each other, the mutual attraction is so strong that the electricity will pass from the one to the other through the intervening air, and a spark called the *electric spark* is seen; a sharp crack is also heard. Lightning is simply the 'spark' produced on a large scale when two clouds, one positively, the other negatively electrified, or when an electrified and an unelectrified cloud come near each other. What is known as *current* or *galvanic electricity* is developed by the chemical action of certain solutions and certain metals. Thus if a piece of amalgamated zinc and a piece of silver be immersed in a weak solution of sulphuric acid, as soon as they touch each other bubbles will be seen to rise from the surface of the silver piece. Separate the pieces, and the bubbles cease. These bubbles are hydrogen gas. A *current* of electricity was produced when the zinc and silver were in contact; it decomposed the water into its constituent oxygen and hydrogen. The oxygen was given off at the zinc, and uniting with it of course did not rise in bubbles like the hydrogen. Copper and zinc are the metals chiefly used, and a *galvanic battery* is a combination of a number of cells properly arranged and connected with each other. Another kind of electricity is called *animal electricity*, *e.g.* the torpedo of the European seas, gymnotics or electric eel of South America. The principal effects of electricity are (1) evolution of light and heat, (2) great mechanical force, (3) affects also nervous systems of animals, causing the muscles of animals newly killed to contract. But the most important is its decomposing power, resolving the compounds that defy any other force.

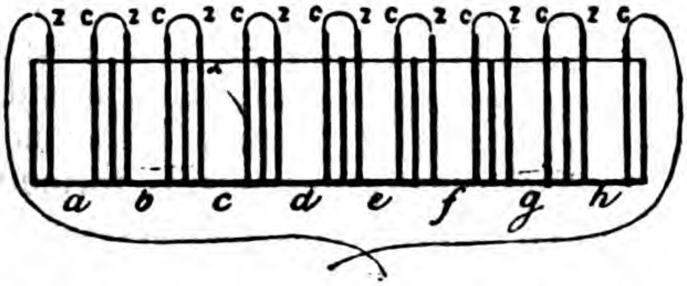


Fig. 7. Showing the arrangement of the zinc and copper in a galvanic battery, of which *a, b, c, d, e, f, g, h,* are cells.

CHAPTER IV.

ON CHEMICAL ACTION—THE FORMATION OF BINARY COMPOUNDS—BREAKING UP OF COMPOUND MATTER INTO SIMPLER FORMS—THE CHEMICAL ELEMENTS.

27. **Chemical Action.**—In art. 17 we briefly explained the meaning of the term 'chemical affinity.' When the affinity between two or more substances is allowed to exert itself, *chemical action* is said to take place, and a new substance is formed by the chemical union of the original substances, differing partly or entirely from them in properties. For instance, sulphur has neither taste nor smell, and does not act on vegetable colours. Oxygen, also, is equally inefficient in other respects. But when sulphur and oxygen are chemically united, the compound thus formed (sulphuric acid) is intensely acid, reddens blue vegetable infusions, and readily combines with various substances for which the sulphur and oxygen individually evinced no affinity. *Chemical combination* must not be mistaken for mere *mechanical mixture*, as there is a wide difference between them. For instance, by the former an entirely *new* substance is formed by the union of two or more substances. From this new substance no mechanical operation can ever recover the original substances. The latter produces no change whatever in the properties of the

substances mixed, which can be easily distinguished and recovered separately by mechanical means. Thus if we heat powdered sulphur and copper filings, an essentially different substance is formed by their chemical union, and the sulphur and copper can never be recovered from this compound by mechanical means. But if the powdered sulphur and copper filings be simply mixed together, an apparent change, in colour at least, takes place. Microscopic examination, however, shows that the particles of sulphur and copper, although lying side by side, still retain their individuality, and can be easily separated. We cannot, then, resolve chemical compounds into their original substances or elements by any mechanical operation whatever; but we can do so indirectly by chemical means, by taking advantage of the unequal strength of the mutual affinities of bodies. Thus suppose we wish to resolve a compound AB into its elements A and B. With the compound AB we mix a new substance C, which has a stronger affinity to B than A has, consequently the chemical union of A and B is dissolved; B joins C, forming a new compound BC. The other element A is thus left separate. Again, to obtain the element B in a separate state, we must mix with the compound AB another substance, which by its stronger affinity attracts A, and so B is left separate. Chemical action, then, manifests itself in two ways,—first, in the combination of two or more bodies; secondly, in the separation of the proximate or ultimate elements of a compound body. When we wish to examine a compound body, we may do so by decomposing it into its several elements: this process is termed *analysis;* or we may take the same elements, and combine them to form a similar compound: this is termed *synthesis.* When the former has been carried on as far as possible, the compound has been resolved into its most simple principles or elements. Thus marble may be decomposed into two substances, lime and carbonic acid. The lime and carbonic acid can be further decomposed, the former into calcium and oxygen, and the latter into carbon and oxygen. And as calcium, oxygen, and carbon have not yet been decomposed into any simpler substances, they are said to be elementary bodies, or *elements.*

As we said before, chemical action effects nearly always a complete change in the properties of the original substances. If one of the elements, however, has some very distinctive property, it may be traced through all its compounds. Thus all the salts of ammonia, which is volatile, are also volatile. Certain other changes also accompany chemical action. (1) The *specific gravity* of the compound is generally greater than the mean of that of its elements. (2) The *temperature* rises or falls. Thus equal weights of water and oil of vitriol at 50° F., if suddenly mixed, are heated to 212° F., and a mixture of sea-salt and snow becomes so cold as to freeze almost any liquid immersed in it. (3) The *forms* of bodies are often changed. Thus if we apply a lighted match to gunpowder, the gunpowder passes at once from the solid to the gaseous state. Again, the two gases, muriatic acid and ammonia, when chemically combined, form a white salt. (4) Change of *colour.* Thus one hundred parts of quicksilver and four parts of oxygen invariably give a black compound. In all these changes there is no destruction of matter. Its form and properties only are altered by chemical action. There is no loss of matter in combination or decomposition; nor, on the other hand, is there any gain. For if a compound body be decomposed, its component elements will be found to weigh exactly as much as they did before combination. Frankland thus summarizes the modes of chemical action:—(1) By the *direct combination* of elements or compounds with each other; (2) by the *displacement* of one element or compound radical in a body by another element or compound radical; (3) by a *mutual exchange* of elements or compound radicals in two or more bodies; (4) by the *rearrangement* of the elements or compound radicals already contained in the body; (5) by the *resolution* of a compound into its elements, or into two or more less complex compounds.

28. **The Formation of Binary Compounds.**—A *compound* body is made up of two or more elementary substances, or *elements*, chemically combined with each other. If the compound be formed of two elements, it is called a *binary* compound; if of three, a *ternary*, and so on. Thus water is a binary compound composed of two gases, oxygen and hydrogen. Common salt is also a binary compound, consisting of chlorine gas and sodium. Most of the binary compounds are either *bases* or *acids*. Bases of which oxygen forms a part are called *oxides*, and an acid of which oxygen also forms a part is named after the element, to which the oxygen is united with the suffix *-ic* added. For instance, a compound of copper and oxygen is called an *oxide of copper*, but as the proportion of oxygen varies in the different oxides, special prefixes are used. Thus *protoxide* of manganese means the *first* oxide, or the one in which there is the least quantity of oxygen; *binoxide*, the *second* oxide, etc.; *peroxide*, the oxide containing *most*

oxygen. The *acids* containing most oxygen only are distinguished by the suffix *-ic*, those containing lesser quantities take the termination *-ous*. Thus *sulphurous* acid contains less oxygen than *sulphuric* acid. If hydrogen or sulphur forms part of the acid, the syllables *sulpho* or *sulph*, or *hydro* or *hydr*, are prefixed to the name of the element to which they are joined. Thus the acid composed of hydrogen and chlorine is called *hydrochloric* acid. Those binary compounds which are neither acids nor bases generally have the suffix *-ide* or *-uret* added to the name of the element. Thus compounds of chlorine are called *chlorides*. We must now draw attention to the characteristic feature of chemical action, and its exemplification in the formation of binary compounds. Gravity operates between any number of masses, whatever their size and distance from each other. Cohesion also exerts itself between any number of particles. Chemical affinity differs from both, chiefly in this, that elementary substances unite chemically only in certain definite proportions. Every elementary substance has a certain *combining weight*, as it is called. Thus the combining weights of hydrogen and oxygen are as 1 is to 8, so that the compound of hydrogen and oxygen (water) consists by weight of 8 parts of oxygen to 1 part of hydrogen. When a substance combines with another in more than one proportion, its quantity in the second compound will be an exact multiple of what is in the first. Thus carbonic oxide consists of 12 parts of carbon and 16 of oxygen; but the second compound, carbonic acid, consists of 12 parts of carbon, and 32 parts (that is, exactly twice) of oxygen. There are no intermediate compounds whatever. It is only in the proportion indicated by their combining weights that combination will take place between elementary or compound substances. An excess in the quantity of any of the elements is sure to be left out of the compound; for if we mix, say, 11 parts of oxygen to 1 part of hydrogen by weight, and ignite the mixture, chemical union will only take place between the 1 part of hydrogen and the 8 parts of oxygen, the 3 parts of the latter in excess being left out. The following is a short list of the principal binary compounds:—

Name.	Parts by Weight of.	
Water,	Hydrogen, 2.	Oxygen, 16.
Magnesia,	Magnesia, 24.	Do.
Lime,	Calcium, 40.	Do.
Soda,	Sodium, 46.	Do.
Carbonic Acid,	Carbon, 12.	Oxygen, 32.
Chloride of Lime,	Calcium, 40.	Chlorine, 71.
Silica,	Silicon, 28.	Oxygen, 32.
Common Salt,	Sodium, 23.	Chlorine, 35.
Carburetted Hydrogen,	Carbon, 24.	Hydrogen, 4.

29. **Breaking up of Compound Matter into Simpler Forms.**—As we remarked in art. 27, the nature of chemical compounds can be determined either *synthetically*—that is, by combining the same elements to produce a similar compound—or *analytically*, by 'breaking up' compound bodies into their original elements. When analysis is carried out as far as possible,—that is, the compound has been resolved into its elements,—it is termed *ultimate analysis*. But when a compound, such as sulphate of potassium, is composed of other compounds, its first stage of resolution is called *proximate analysis*. Professor Roscoe gives the

following illustration of the decomposition of a binary compound. A small quantity of mercury oxide is introduced into a test-tube and heated in a gas flame; when hot, the oxide gradually decomposes, a grey deposit of metallic mercury in small globules collects upon the cooler parts of the glass, whilst the tube becomes filled with colourless oxygen gas, whose presence can be demonstrated by the rekindling of a glowing chip of wood plunged into the tube. On continuing the heat, the whole of the mercury oxide is found to be split up into the two elements, mercury and oxygen, which together weigh exactly as much as the oxide from which they are obtained. Water, also a binary compound, may be decomposed by a current of voltaic electricity, and its constituent gases, oxygen and hydrogen, evolved at separate poles. But the 'breaking up of compound matter into simpler forms' is mainly due to *elective affinity*—that is, every body, chemically speaking, attracts other bodies unequally. This being the case, whenever, say, a binary compound is mixed with a substance which has a stronger affinity for one of its elements than the other element has, the compound is decomposed, one element is left separate, while the other combines with the new substance. Thus potassium thrown into water attracts the oxygen of the water so strongly as to decompose it, and, combining with the oxygen, forming potassium oxide, the hydrogen is liberated.

30. **The Chemical Elements.**—The elementary bodies or elements at present recognised consist of 50 metals and 13 non-metals, the former term embracing such elements as silver, gold, iron, etc., the latter those which at the ordinary temperature are gases, such as oxygen, etc., and other solid bodies,

as sulphur, etc. Only a few of these elements enter largely into the composition of the globe, and are very irregularly distributed, some being found in the greatest abundance, others only in very minute quantities. The air, for instance, consists mainly of two elements, oxygen and nitrogen in a free state (that is, simply mixed, not chemically combined). Nearly one-half of the solid crust of the earth, more than one-fifth of the air, and about eight-ninths of all the water on the globe are formed of one element, oxygen. The following are the most abundant elements, and consequently the most important:—*Oxygen*, *hydrogen*, *nitrogen*, *carbon*, *sulphur*, *phosphorus*, and *silicon*. Oxygen readily combines with other bodies; respiration and combustion are entirely dependent on it; altogether makes up nearly half the weight of the earth. Hydrogen combined with oxygen forms water, and also enters largely into the composition of all animals and vegetables. Nitrogen will not support combustion or animal life, but serves to dilute the too-powerful oxygen. Carbon is essential to the formation of organic substances. Silicon in combination with oxygen, as silica, enters largely into the composition of most of the rocks and minerals which form the crust of the globe. Sand, flint, etc. are nearly pure silica. A complete list of the chemical elements is subjoined (p. 48).

LIST OF CHEMICAL ELEMENTS.

NON-METALS.

		Combining Weight.
Arsenic,	(As.)	75
Boron,	(B.)	11
Bromine,	(Br.)	80
Carbon,	(C.)	12
Chlorine,	(Cl.)	35·5
Fluorine,	(F.)	19
Hydrogen,	(H.)	1
Iodine,	(I.)	127
Nitrogen,	(N.)	14
Oxygen,	(O.)	16
Phosphorus,	(P.)	31
Selenuim,	(Se.)	79·5
Silicon,	(Si.)	28
Sulphur,	(S.)	32
Tellurium,	(Te.)	129

METALS.

(Most Common.)

Aluminum,	(Al.)	27·4
Antimony,	(Sb.)	122
Barium,	(Ba.)	137
Bismuth,	(Bi.)	210
Calcium,	(Ca.)	40
Chromium,	(Cr.)	52·2
Cobalt,	(Co.)	58·7
Copper,	(Cu.)	63·5
Gold,	(Au.)	197
Iron,	(Fe.)	56
Lead,	(Pb.)	207
Magnesium,	(Mg.)	24
Manganese,	(Mn.)	55
Mercury,	(Hg.)	200
Nickel,	(Ni.)	58·7
Platinum,	(Pt.)	197·5

METALS—*continued.*

		Combining Weight.
Potassium,	(K.)	39·1
Silver,	(Ag.)	108
Sodium,	(Na.)	23
Strontium,	(St.)	87·5
Tin,	(Su.)	118
Zinc,	(Zn.)	65·2

RARER METALS.

Beryllium,	(Be.)	9·3
Cadmium,	(Cd.)	112
Cæsium,	(Cs.)	133
Cerium,	(Ce.)	92
Didymium,	(D.)	95
Erbrium,	(E.)	112·6
Indium,	(In.)	113
Iridium,	(Ir.)	198
Lanthanum,	(La.)	92
Lithium,	(Li.)	7
Molybdenum,	(Mo.)	96
Niobium,	(Nb.)	94
Osmium,	(Os.)	199·2
Palladium,	(Pd.)	106·6
Rhodium,	(Rh.)	104·4
Rubidium,	(Rb.)	85·4
Ruthenium,	(Ru.)	104·4
Tantalum,	(Ta.)	182
Thallium,	(Tl.)	204
Thorium,	(Th.)	231·5
Titanium,	(Ti.)	50
Tungsten,	(W.)	184
Uranium,	(U.)	240
Vanadium,	(V.)	51·3
Yttrium,	(Y.)	61·6
Zirconium,	(Zr.)	89·6

CHAPTER V.

WATER, ITS COMPOSITION AND DIFFERENT STATES.

31. **Composition of Water.**—Water, chemically considered, is composed of two gases, hydrogen and oxygen, combined in the proportion *by weight* of 8 parts of oxygen to 1 of hydrogen, or *by volume* of 2 volumes of hydrogen to 1 of oxygen. The composition of water was first experimentally determined in 1781 by Mr. Cavendish, and subsequent careful synthetical experiments have only confirmed the conclusion to which he arrived, viz. that 2 volumes of hydrogen unite with 1 volume of oxygen to form water. The composition of water is determined analytically by means of a current of voltaic electricity. A glass vessel is filled with water slightly acidulated with sulphuric acid, so that it may conduct the electricity. In the bottom of the glass is a hole, stopped by a tight-fitting piece of cork or caoutchouc. Through this stopper two platinum wires pass, ending in two small plates of the same metal inside the vessel. Over each of these plates a test-tube, filled with water, is inverted. When the platinum wires are connected with the terminals of a galvanic battery, gas is seen to be given off from each plate, that disengaged at the negative electrode being pure hydrogen, and that at the other pure oxygen. If the tubes be gradu-

ated, the volume of hydrogen will be observed to be double that of oxygen, thus showing that water is composed of 2 volumes of hydrogen and 1 of oxygen. We can also determine the composition of water synthetically by mixing 2 volumes of hydrogen with 1 of oxygen. Upon igniting the mixture, the gases combine with a loud explosion, and water is formed. More accurate detailed experiments show that 100 parts *by weight* of water are composed of 88·89 parts of oxygen and 11·11 parts of hydrogen. Water is never found absolutely pure in nature (the preceding remarks refer to the composition of pure or *distilled* water), and usually contains more or less extraneous substances. Even rain water, the purest of all, contains small quantities of foreign matters, while any considerable body of water always contains more or less solid matter in solution. The latter may be got rid of by *filtration;* but those substances dissolved in it can only be removed by distillation. (Distilled water is simply the steam or vapour of boiling water reconverted into water and collected.) Sea water is rendered salt by the presence of certain substances chemically dissolved in it, common salt being found in the largest quantity. Thus in 1000

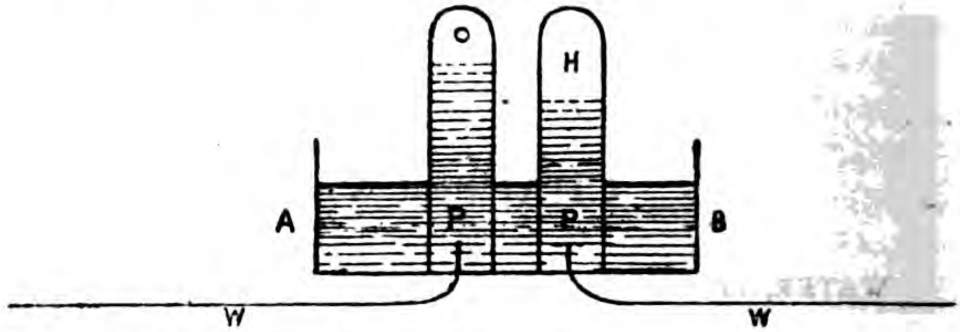


Fig. 8. Apparatus for decomposing water. AB, the glass vessel; PP, platinum plates; WW, wires connected with battery.

parts of sea water about 35 parts are solid matters in solution, and 28 of these parts consist of chloride of sodium or common salt. We shall have occasion to refer again to the composition of sea water and consider it more fully. Fresh water, on the other hand, is so called from the absence of saline ingredients; but, nevertheless, it is far from pure, holding in solution particles of the substances dissolved while percolating through the earth. Sometimes a substance is held in solution in such quantities as to confer upon the water a distinctive character, as in the various kinds of mineral springs. Thus the *sulphureous springs* contain sulphuretted hydrogen; the *chalybeate*, iron, etc.

32. **The Different States of Water.** — Water occurs in nature in three states, viz. the solid, the liquid, and the gaseous; in the first as ice, in the second as water, and in the last as vapour or steam. Its conversion from the liquid into the solid or gaseous state depends upon its temperature. When it is heated to a temperature of 212° F. at sea level, under ordinary atmospheric pressure, it boils and assumes the gaseous form known as steam. This point, which is constant under the same conditions, is called the *boiling point* of water, and simply means that the tension of the vapour is equal to the pressure of the atmosphere; therefore, the higher we ascend, atmospheric pressure diminishes, and consequently the boiling point of water is lowered also. When the temperature of fresh water falls to 32° F., or that of salt water to 28½° F., it assumes the solid state known as ice, the process being accompanied by a sudden expansion which is almost irresistible. Thus iron shells, filled with water, burst when the water freezes. Ice, therefore, is lighter than, and floats on the surface

of water. Other fluids contract on freezing; and if water also obeyed the same law, the lowering of the temperature at any time to 32° F. or $28\frac{1}{2}$° F. would be attended with the conversion of all the water on the globe into solid ice, with what consequences to animal and vegetable life is obvious. In each of these three states water is of immense importance in the economy of nature. Organic and inorganic bodies are partly formed of it; it is essential to the life of animals and plants; and in its various forms has been and is the principal modifying agent in the past and present aspects of the surface of the earth.

CHAPTER VI.

ON THE CHEMICAL AND PHYSICAL CHARACTER OF THE CRUST OF THE EARTH.

33. **The Earth's Crust.**—The use of the term 'crust of the earth' originated in the belief which a few years ago was generally accepted, viz. that the interior of the earth was a molten mass, enveloped by the cooled and hardened solid 'crust.' This belief was based on the fact that a rise in temperature of 1° F. took place for every 50 or 60 feet of descent, and consequently that at a depth of 50 miles or so the heat would be so intense as to fuse all known substances. But when we consider the enormous pressure at that depth, we cannot but conclude that the theory of internal fluidity in its entirety is incorrect. The term 'crust of the earth,' then, can only be appropriately given to the outer portion of the solid surface of the earth as far as can possibly be investigated. Of the interior of the earth we cannot, of course, obtain any direct information. If, therefore, we restrict the term 'crust of the earth' to that portion of the solid surface of which we have any knowledge, it appears very insignificant when compared with the actual dimensions of the earth. But when we consider the ceaseless and extensive changes to which the earth's crust has been and is subject, the

insignificance vanishes, and an intense interest is given to it. Space will not allow us to do more than refer very briefly to the chemical and physical character of the earth's crust.

34. **Rocks.**—All the various materials of which the earth's crust is composed, whether they are rocks in the usual acceptation of the term, implying any hard, stony substance, as granite, or soft and yielding, as clay, or incoherent masses, as gravel or sand or even peat, are geologically termed *rocks.* Every one knows that the materials thus called rocks present numerous differences, but, if closely considered, a general resemblance will be seen between many of them. One of the most obvious differences is that of arrangement, some rocks being arranged in layers or beds one above the other in a more or less horizontal or inclined direction; in others no such regularity of arrangement can be detected. We can therefore conveniently divide all rocks and rock formations into two great classes, —*stratified* and *unstratified,*—the former formed by the action of water, the latter by the action of fire. To these two great divisions, generally speaking, all rocks, however, formed and however subsequently modified, belong.

35. **Stratified Rocks.**—Some rocks, as we have said, are arranged more or less regularly in layers or beds one above another. Such layers are called *strata,* and the rocks so arranged are said to be stratified. All stratified rocks bear evident marks of having been formed by the action of water—that is, the debris or sediment borne down by rivers or abraded by the action of waves, tides, etc., was spread out in layers or beds at the bottom of lakes or seas, the heavier particles of course falling first, and the lighter being uppermost. Thus a section

of the bed of a lake would show a layer of gravel lowest, then sand, then mud. This deposition being

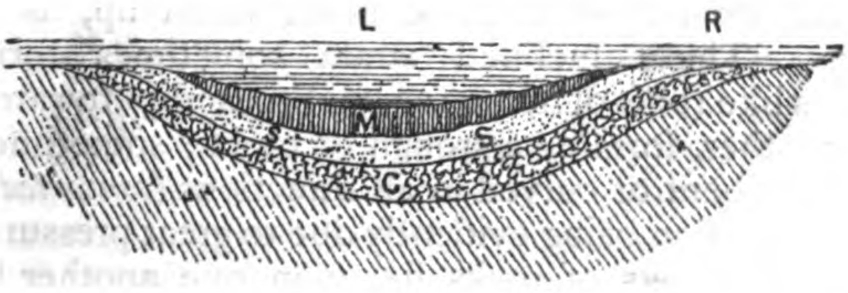


Fig. 9. Showing stratified arrangement of sediment at the bottom of lakes. R, river; L, lake; M, mud; S sand; G, gravel.

carried on unceasingly, thick beds are gradually formed one above the other, and in time the sediment thus arranged is consolidated into hard rocks, hence called *sedimentary rocks.* All rocks, then, formed by the deposition of sediment in water are called *aqueous*, *stratified*, or *sedimentary rocks.*

36. **Unstratified Rocks.**—Other rocks bear no marks of stratification, but on the contrary are of no determinate form, and are found sometimes overlying or bursting through the stratified rocks, or spread over the surface in large irregular masses. They are therefore termed *unstratified.* As stratified rocks bear evident marks of aqueous origin, so unstratified rocks are clearly of igneous origin, presenting unmistakeable signs of having once been in a state of fusion. They are therefore also called *igneous* or *volcanic* rocks. Their origin is further proved by their crystalline texture, while stratified rocks are non-crystalline.

37. **Relative Arrangement of Stratified and Unstratified Rocks.**—The original position of the layers of sediment deposited over the bottom of lakes and seas would necessarily be more or less

horizontal; but when these horizontal strata were broken up by violent volcanic eruptions, they were made to assume more or less *inclined* positions, sometimes almost vertical, being tilted up, as it were. These inclined strata sometimes form ridges like roofs of houses; sometimes 'dip' towards each other, forming a trough or basin; sometimes they are bent or curved in all directions (*contorted*), the contortion being evidently due to great pressure. When two sets of rocks lie upon one another in parallel order, they are said to be *conformable;* but if one overlies the other at a different angle, it is said to be *unconformable.* If all the strata of a particular district slope in the same general direction, they are said to be *monoclinal;* but if they dip in different directions, *periclinal.* ***Escarpments*** are the steep terminals of highly-inclined strata. Detached masses, presenting the same formation as the adjoining strata, are termed *outliers.* Stratified rocks are sometimes *disrupted*, if we may say so—that is, igneous matter being forced up through them, breaks their continuity, and otherwise alters them. If the igneous matter be ejected in sufficient quantities, it spreads over the surface in irregular

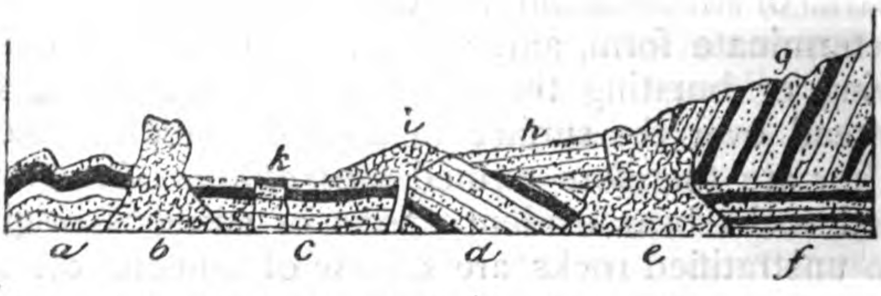


Fig. 10. Stratified and unstratified rocks. *a*, Contorted strata; *b*, *e*, unstratified rocks; *c*, horizontal strata, dislocated in *k* by a fault; *d*, *g*, *h*, inclined strata; *g*, *f*, *h*, *d*, unconformable strata; *i*, intrusive igneous rocks.

amorphous masses; and should these masses be subsequently covered by new sedimentary strata, they are termed *interstratified.* Other igneous rocks are also found between the aqueous strata, but in such a manner as to show that the *intrusion* took place after the strata had been formed. When continuous horizontal or inclined strata has been broken up or thrown out of its original position, or otherwise displaced, such disturbances are termed *dislocations.* Dislocations are variously called, as *faults*, *slips*, etc.; or if the *fissures* be filled up, *dykes*, *lodes*, *veins*, etc. That these alterations of the original positions of stratified rocks are mainly due to igneous agency is evident, fissures being generally filled up with igneous matter squirted up, as it were, from below.

38. **Chemical Composition of Rocks.**—Chemically considered, the earth's crust mainly consists of only eight elements, variously combined, or rarely in their simple state. Nearly all known minerals contain *oxygen*, which is present in such a large proportion that it forms at least one-half of the solid crust of the earth. Next to oxygen, *silicon* is the most abundant element in nature, forming about one-fourth of the rocks of which the earth's crust is composed. Thus nearly three-fourths of the solid substances found in the earth consists of various combinations of two elements only, oxygen and silicon. The latter is never found in a simple state in nature, but always in combination with oxygen as *silica*, which occurs nearly pure in quartz, flint, sandstone, etc. Silicon also combines with many of the metals and oxygen, forming metallic *silicates*, which are by far the most abundantly-occurring minerals. The next in order is *aluminum*, which occurs in large quantities com

bined with oxygen and silicon in the older rocks, in many crystalline minerals, and in marl, slate, and clay. *Calcium* also forms a very considerable portion of the rocks of which the earth's crust is composed. It occurs in combination with oxygen as lime, and with carbon and oxygen as carbonate of lime or chalk, limestone, coral, marble, etc. *Iron* is scarcely ever found naturally in a pure state, but as an ore, that is, combined with other elements, such as oxygen, carbon, silicon, etc. *Magnesium*, in combination with carbon and oxygen, as magnesium carbonate, is found in large quantities combined with carbonate of lime, forming magnesian limestone. *Sodium*, also, is never found free, but its compounds are widely diffused. Rock salt is a chloride of sodium, and is sometimes found in masses of a hundred feet or more in thickness. *Potassium* is found as a potash in several igneous rocks, chiefly in felspar, in combination with silica. *Carbon* is found pure, in small quantities only, as diamond and graphite, and more or less pure in charcoal and coal. Carbon enters largely into the composition of all organic bodies, and is the most important chemical disintegrating agent, dissolving limestone rocks, thus forming carbonate of lime, which forms the cementing material in conglomerates, sandstones, etc. *Oxide of iron*, also, enters largely into the composition of many rocks, from which it is dissolved by the action of water, and precipitated among gravel, etc., forming conglomerates. Other elements, such as *gold*, *silver*, *platinum*, *copper*, etc., are not found in such large proportions as the preceding, and only in certain localities. They are occasionally found in a pure state, but most of the metals are found as ores, which are oxides or sulphurets of the metals. The following table shows the percentage in which the different elements occur in the earth's crust, or, in other words, the average chemical composition of 100 parts by weight of the earth's crust:—

Oxygen, about one-half,	50·0
Silicon, about one-fourth,	25·0
Aluminum, about one-sixteenth,	6·0
Calcium, about one-twentieth,	5·0
Iron, about one-twenty-fifth,	4·0
Magnesium, about one-thirtieth,	3·0
Sodium, about one-fortieth,	2·5
Potash, about one-fortieth,	2·5
Various other elements, about one-fiftieth,	2·0
	100·0

39. **Mineral Composition of Rocks.**—The most abundantly-occurring minerals are composed of silica, either in a simple state or in combination with various bases, such as lime, soda, potash, alumina, etc. *Quartz* is nearly pure silica (silicon and oxygen), and is the most abundant of all. It occurs in two forms as silica, viz. as rock crystal and chalcedony, and as silica and water as *hydrated quartz* (hydrogen silicate). Free-coloured quartz forms many of the precious stones, such as ruby, agates, etc. *Felspar* occurs in various forms, of which *orthoclase* or *potash felspar* (potash, silica, and alumina) is the most abundant, and is one of the constituents of granite. *Albite* or *soda felspar* (soda, silica, and alumina) is usually white in colour, hence its name; it occurs in granite, syenite, and greenstone. *Anorthite* or *lime felspar* (lime, silica, and alumina) occurs as white, semi-transparent crystals. *Mica* is also one of the constituents of granite, and occurs in elastic laminæ,

which have a glistening metallic lustre. Chemically considered, mica is a complex compound, consisting of potassia, magnesia, oxide of iron, calcium monoxide or lime, and silica. Mica, felspar, and quartz are the constituents of common granite. Mica and quartz form *mica schist*. *Talc* (silica and magnesia), with felspar and quartz, forms talcose granite, and it also occurs in beds of talc slate. *Serpentine* contains magnesia, is generally green in colour, and is occasionally found in masses. *Chlorite*, like talc and serpentine, is a silicate of magnesia. *Augite* (silica, magnesia, lime, and small quantities of oxide of iron and alumina) occurs in the largest quantities in rocks which contain little silica; while *hornblende* (silica, alumina, magnesia, lime, and iron oxide) occurs in the more silicious rocks. Of *sulphates*, the principal are *gypsum*, a sulphate of lime, and *barytes*, a sulphate of baryta. The latter occurs in nature in a crystalline state as heavy-spar; the former, after losing its water by heat, is known as plaster of Paris. Of the *carbonates*, *calcite* is a crystallized form of carbonate of lime. *Hematite*, *magnetite*, and *limonite* are oxides of iron. *Iron pyrites*, a ferrous sulphide, are found in large quantities, and much used in chemical works. All the above minerals contain oxygen. A few, however, do not, but, being found only in small quantities, can scarcely be classed as rock-forming minerals. Such are the simple substances, *sulphur*, *diamond*, and *graphite*; or the compounds, *fluor spar* and *rock salt* (chloride of sodium).

40. **Classification of Rocks.**—In arts. 34–37 we said that the rocks of which the earth's crust is composed may be broadly divided into two great classes, the *stratified* and the *unstratified*, the

former due to the action of water, the latter to that of fire. But there are vast masses or beds of rocks which are not, strictly speaking, due to the action of either water or fire, but are either chemically formed or derived from organic substances, such as limestone and coal. We shall therefore be more accurate in our classification if we refer to the same class all those rocks due to the action of the same cause, or, in other words, of the same formation. With this view, we shall proceed to consider very briefly—(1) *mechanically-formed* rocks, (2) *igneous* or *fire-formed* rocks, (3) *organically-formed* rocks, (4) *chemically-formed* rocks, and, lastly, (5) *metamorphic* or *changed* rocks. Our space will not allow us to give more than a short notice of the typical rocks in each class.

41. **Mechanically-formed Rocks.**—Under this heading we include all those rocks whose formation is the result of merely mechanical operations, as distinguished from chemical and igneous action. All mechanically-formed rocks are due to the action of water or air. We may call the former *aqueous* or *sedimentary* rocks, the latter *aerial* or *Æolian* rocks.

42. **Sedimentary Rocks.**—Sedimentary rocks, as the term implies, are simply consolidated sediment deposited over the bottom of lakes and seas, and are thus due to the mechanical action of water. And as all sedimentary matter deposited in water is spread out over the bottom in more or less uniform layers, one above the other, sedimentary rocks bear indisputable marks of their aqueous formation in their *stratification*, as well as in the attrition to which the solid particles have been subjected, and which could not have been performed by any other natural agent Typical

rocks of this division are *conglomerate*, *sandstone*, and *shale*.

43. **Typical Sedimentary Rocks.**—*Conglomerates* or *pudding-stones* are composed of gravel and pebbles, cemented together by carbonate of lime or oxide of iron or silica, which, being held in solution, is deposited among the stones when the water is evaporated. Conglomerates may consist of particles of any particular kind of rock, or a mixture of particles of several different kinds. If the particles are nearly all quartz, the rock is called *quartzose*. Conglomerates, however, are generally named after the cementing material. Thus if it be iron, they are called *ferruginous;* if lime, *calcareous;* if clay, *argillaceous*, etc. If the imbedded particles still retain their angularity, not having been subjected to attrition, the conglomerate is said to be *brecciated*. *Sandstones* also consist of particles consolidated by pressure or cemented together by oxide of iron, etc., and so resemble conglomerates closely in mode of formation; but with this difference, that while conglomerates are simply consolidated gravel, sandstones are simply consolidated sand. *Shale* also is simply consolidated mud of a more or less laminated structure. If sand be mixed with the mud, it forms a *shaly sandstone*.

44. **Aerial Rocks.**—Sedimentary rocks, as we have seen, are all due to the action of water in various forms, as rain, springs, rivers, waves, tides, and ocean currents. By the term *aerial* we mean those causes engaged in the formation of rocks depending upon the air, such as air-weathering, winds, desiccation or drought, frosts, and even ice action. Thus rocks crumble and waste away in minute particles which are blown about by the wind, accumu-

lating along the coasts, as on the west coast of France, or far inland, as in the Asiatic and African deserts. Both desiccation or drought and frosts disintegrate the surface rocks, and the resulting *debris* often accumulated in vast quantities at the bases of mountains are examples of this mode of formation. These rocks, however, are not the result of the mechanical action of water and air only, but are partly due to the chemical action of these agents. The latter will be considered farther on.

45. **Igneous or Fire-formed Rocks.**—We have already described the formation and mode of occurrence of igneous rocks. In their composition igneous rocks vary considerably, some being finely, others coarsely crystalline, but all containing felspar as a base. Typical rocks of the various groups into which igneous rocks are usually divided are granite, basalt, felstones, obsidians, trachytes, and scoriæ.

46. **Typical Igneous Rocks.**—*Granite* is by some geologists considered as a metamorphic rock, by others as an igneous rock; it occurs, however, both as a metamorphic and as an igneous rock. It is generally composed of felspar (potash-, soda-, or lime-felspar, usually potash-), quartz, and mica. What is known as *porphyritic* granite contains large crystals of felspar. *Talcose* granite contains talc instead of mica. *Graphic* granite is an irregularly-laminated compound of felspar and quartz. *Syenite* is composed of felspar, quartz, and hornblende. *Basalt* is a mixture of felspar, augite, iron, and sometimes olivine; basaltic rocks are characterized by their columnar structure. *Felstones* are composed of silica and potash-felspar, and are hard, compact, and less crystalline than basalt. *Obsidians* or *volcanic*

glass, so called from its resemblance to coarse glass, is, comparatively speaking, a modern volcanic rock; a porous variety is called *pumice*. *Trachytes* are rough-grained, contain small crystals of felspar, and are a modern volcanic product. *Scoriæ* are fragments of rocks ejected from volcanoes, often cemented and solidified, forming *volcanic tuff*.

47. **Organically-formed Rocks.** — The rocks which we include in this class have been formed partly or entirely from the organic remains of plants and animals, the latter being chiefly minute marine organisms, which, being covered over by newer deposits, were consolidated into rocks by pressure and chemical action. Thus coal is but mineralized vegetation, and a rock called tripoli is composed of the silicious frustules of a minute variety of sea plants. Chalk and many other kinds of limestone are also formed of accumulations of skeletons, shells, etc. of minute marine organisms, vast masses of calcareous shields being secreted by the *foraminifera*, while the *polycytinæ* and *diatomaceæ* furnish masses of minute silicious cases. But the most important organic agents are the *coral zoophytes*, which form vast reefs sometimes hundreds of miles in extent. It is true that the bones and other remains of land animals occur in many rock formations, but rarely in such quantities as to form rocks. Of the organically-formed rocks, we may select coal, peat, chalk, limestone, and coral as typical examples.

48. **Typical Organically-formed Rocks.**—*Coal* is composed of vegetable matter; the original plants, having been submerged and covered with other deposits, were thus subjected to great pressure, and, being also chemically acted upon, were ultimately more or less mineralized. There are many

varieties of coal, from the recently-formed *lignite*, wood or brown coal, *bituminous* or common coal, and *cannel* coal, to *anthracite*. *Peat* is simply the first stage in the metamorphism of vegetables, and the gradations from peat to lignite, and from lignite to coal, clearly show that they are but different stages in the gradual mineralization of vegetables, the extreme stages of which are seen in crystallized and pure carbon as diamond and plumbago. Anthracite is a *non-bituminous* variety, burning without flame or smoke; but all the more common kinds (caking coal, cannel coal) are *bituminous*, and give off both flame and smoke in burning. The gradual alteration in composition may be seen from the fact that carbon forms 50 per cent. of woody fibre, 60 per cent. of peat, 66 per cent. of lignite, 74 per cent. of common coal, 85 per cent. of cannel coal, and 94 per cent. of anthracite. *Chalk* is the general term for soft, earthy kinds of limestones, and is mainly composed of microscopic calcareous remains of minute marine organisms. *Limestones* are simply accumulations of the remains of minute sea animals, solidified by chemical action under great pressure. There are many varieties, all of which have a base of carbonate of lime—that is, lime and carbonic acid. The softer and more earthy kinds are called *chalk*. Other varieties are *dolomite*, a crystalline variety of *magnesian limestone* (composed of carbonates of magnesia and lime); *carboniferous* or *mountain limestone*, formed of coral, shells, etc. A fine variety of carbonate of lime is called *calcareous alabaster*, and the same of sulphate of lime or *gypsum*, *gypseous alabaster*. *Coral*.—The coral reefs of the Pacific and Indian Oceans are mainly formed by the agency of minute marine animals,—the coral zoophytes,—of which there are many varieties. The proper reef-building polypi (*actinozoa*) do not flourish at greater depths than twenty or thirty fathoms. In composition coral rock resembles solid white limestone, sometimes quite compact, and sometimes with the coral masses intact, and the spaces between filled up with pieces of coral and other marine debris. If the reef encircles a shallow lagoon, it is called an *atoll;* if it surrounds a lagoon, with an island in the centre, it forms a *fringing reef;* and if partially encircling an island, or chain of islands for considerable distances, it forms the true *barrier reef.* The depths of the different reefs vary considerably; thus inside a fringing reef the water is generally about 100 feet deep, while outside some barrier reefs it exceeds 1800 feet in depth. Now, as the reef-building polypi cannot live at greater depths than about 100 feet, it follows that the beds of those seas in which the coral reefs exceed 100 feet in depth must have gradually subsided. If the subsidence had been sudden, the zoophytes, of course, would have been sunk to depths in which they could not live; consequently the corals must have begun to grow in water of not more than 100 feet deep, and have kept on growing upwards to the surface while the sea bottom gradually subsided; so that in the same locality all three kinds of reefs would appear in lapse of ages, first a *fringing reef* encircling the island, then a *barrier reef* as the island gradually sank, and lastly, when the island is completely submerged, as an *atoll.*

49. **Chemically-formed Rocks.** — Many of the rocks generally described as 'mechanically formed' are, however, partly formed by a chemical process; so that we cannot fix definitely the limits of these

two classes of rocks, which resemble each other chiefly in being generally deposited in or by water. Thus the deposition of salt, nitrates of soda, of potash, etc., over the bottom of salt lakes, or flat muddy shores, or alluvial inland plains, etc., are purely chemical processes, the salts being slowly precipitated during the gradual evaporation of the water; on the other hand, the deposition of sediment is a purely mechanical process. Coral reefs, however, are formed partly mechanically and partly chemically. The extent of chemical action on rocks may be inferred from the fact that fully 40 per cent. of many igneous rocks (such as obsidians, basalt, etc.) is removed by the action of alkaline salts. Waters of infiltration generally hold these salts in solution, and therefore decompose the rocks through which they percolate. Rocks also act chemically on each other, under certain conditions. Vast deposits of lime are also chemically formed. The water percolating through calcareous strata holds an excess of carbonate of lime. On the evaporation of the water, the lime is deposited on the ground. This is always taking place in caves and hollows underground, which may ultimately be filled with sponge-like masses of limestone. Besides lime, silex is similarly deposited around thermal springs, being held in solution by the water while hot; but when the water cools, the silex is deposited in incrustations, often of very great thickness. As typical examples of chemically-formed rocks, we will mention calcareous deposits, silicious sinters, and rock salt.

50. **Typical Chemically-formed Rocks.**—*Calcareous* deposits are found in caves, and are formed by the continual dropping of water from the roof and sides, which, in percolating the strata above,

became charged with carbonate of lime. Each drop just before falling parts with a portion of its lime, which, growing gradually, at last forms an icicle-like pendant (*stalactite*) adhering to the roof. The drop, after falling on the floor, parts with another portion of, if not all, its lime. Thus little protuberances are gradually formed, called *stalagmites*. The stalactites and stalagmites, continually growing towards each other, may in time meet; and thus the whole cavern may be completely filled up with columnar or honey-combed masses of limestone, which often crystallize. *Travertine*, *calc tuff*, *calc sinter*, and other calcareous deposits are formed in the same way. *Silicious sinters* are composed of silica and water or hydrated quartz. They are found around hot springs like the geysers of Iceland, etc., and are formed by the deposition of the silex held in solution in the water while hot, but parted with on cooling. *Rock salt* (sodium chloride) is found in cake-like masses, sometimes nearly 100 feet thick, and usually in association with gypsum. Beds of rock salt have evidently been formed by the gradual precipitation of the salt during the evaporation of the water in which it was dissolved. From various considerations it is probable that the contiguous strata of rock salt and gypsum were deposited in inland seas.

51. **Metamorphic Rocks.**—Many rocks, although still retaining evident marks of stratification, have been since their formation so changed and altered by the agency of heat, chemical action, or otherwise, that they cannot be appropriately described as stratified, nor on the other hand, although often highly crystalline, as igneous rocks. Hence they are termed *metamorphic*—that is, altered or changed rocks. The transforming action to which these

rocks have been subject is generally evinced by a more or less crystalline texture given to them. Thus some metamorphic rocks are as distinctly crystalline as some of the igneous, but still as definitely stratified as the sedimentary. In other metamorphic rocks, marks of stratification are not so clear, and sometimes altogether wanting, so that their true character is scarcely distinguishable. The four principal groups of metamorphic rocks are well typified by gneiss, quartzite, mica schist, and clay slate.

52. **Typical Metamorphic Rocks.**—*Gneiss* is composed of the same materials as granite,—that is, quartz, felspar, and mica,—but differently arranged. Gneiss also bears evident marks of stratification, and is never found, like granite, in dykes or veins, but nearly always occupies positions similar to those of sedimentary rocks, thus positively proving its original aqueous formation. *Quartzite*, or quartz rock, is simply an altered sandstone, the quartz grains having evidently been in a state of fusion, which caused them to adhere, forming a mass of pure quartz. *Mica schist* is composed of alternate layers of mica and quartz, and is often finely laminated. *Clay slate* (roofing slates) is simply hardened clay or shale, and readily splits into thin plates or laminæ.

CHAPTER VII.

ON THE TEMPERATURE OF THE INTERIOR OF THE EARTH.

53. AT one time it was generally believed that the crust of the earth was but a thin film enveloping an interior highly-incandescent or molten mass. This view was based on the ground that below the stratum of invariable temperature (60 to 90 feet) the temperature increases on an average by 1° F. per every 50 or 60 feet of descent. At this rate at a depth of 28 miles the temperature would be 2400° F. At this temperature such rocks as basalt, porphyry, etc., would be fused. At 50 miles, again, it would be 4500° F., a greater degree of heat than that required to fuse platinum, while at 100 or 150 miles the heat would be such that the hardest known substances would be instantly fused. But in thus arguing, the fact that substances do not fuse so readily under pressure as they do when free is not sufficiently considered. And when we reflect on the immense pressure at a depth of 20, 50, or 100 miles, we may reasonably conclude that the substances found at these depths may, notwithstanding the regular increase of heat downwards, still retain their normal state—that is, those substances which are solid at the surface under the ordinary atmospheric pressure at the ordinary temperature. may still be solid at a depth of 100

miles or more, as the greater heat to which they are subject is more than balanced by the greater pressure of the overlying strata. This method of explaining what really is and ever will be unknown to us, if carried to extremes, leads us to a conclusion which is not countenanced but rather disproved by many natural phenomena—that is, if the pressure is such that the earth is really solid throughout, how and whence are the immense quantities of molten matter ejected during volcanic eruptions formed and derived? What is the cause of earthquakes? So that, from these and many astronomical observations, we cannot conclude that the earth is uniformly solid. Volcanic and other natural phenomena, which prove the existence of high interior temperature, are explained by supposing that immense irregular cavities or chambers exist at varying depths within the crust, filled with molten matters, which, being compressed by the subsidence or upheaval of the contiguous rocks, or excited by the introduction of water (which is instantly converted into elastic steam), is displaced, and either simply pushes the overlying strata upwards, producing disturbances of the earth's surface crust (earthquakes), or bursts through the overlying strata to the surface (volcanic eruptions). The latter theory is now generally accepted, as by its means all igneous phenomena—volcanoes, earthquakes, hot springs, etc.—can be intelligently explained and accounted for. Thus we see that the supposition that the interior mass of the earth is more or less solid, as distinguished from a state of molten fluidity, is not incompatible with the existence of a high degree of temperature in the interior of the earth. It is evident, however, that there are vast cavities or chambers filled with molten matter at uncertain depths within the earth's crust, and that the disturbance of these molten reservoirs is the prime cause of volcanic phenomena and earthquakes. That this interior heat is not derived from the sun is evident, and also that it does not sensibly affect the surface temperature of the earth, owing to the weak conducting powers of the rocky substances of which the earth's crust is composed. But although the evidence as to the existence of great interior heat is indisputable, we cannot determine its degree, nor with any certainty its rate of increase, from the stratum of invariable temperature downwards to the earth's centre, as it varies considerably in different places. Thus in an Artesian well in Wurtemburg it is as much as 1° F. for every 19 feet of descent. In the borings at Creuzot the increase was 1° F. for every 55 feet of descent down to 1800 feet, and below that 1° F. in every 44 feet. In some mines in Central Germany, however, the increase is only 1° F. for every 76 feet of descent, and in the Dukinfield coal pit near Manchester only 1° F. in 89 feet. This, then, is conclusive, that the temperature of the interior of the earth is high, but that this high temperature does not necessarily imply that the interior mass of the earth is in a molten state, the 'crust' being but the hardened shell, as it were; and further, that although the influence of a high interior temperature is scarcely perceptible as regards the surface temperature, all climatic and seasonal changes being entirely due to solar influence, yet it is undoubtedly the cause of earthquakes, volcanic disturbances, hot springs, etc. We propose to consider very briefly these perceptible effects of the interior heat of the globe in the two following chapters. As to the origin of the interior heat of the globe, some affirm that the earth was once in a condition of great heat, and, gradually cooling by radiation into space, its surface was first hardened, and consolidating deeper and deeper, formed the 'crust' of the earth, which according to this theory thickens in proportion as the melted interior mass or nucleus is cooled. Others assert that, while it may be true that the earth was once in a condition of great heat, yet the present interior heat is mainly due to magnetic and electric action, and many well-founded observations seem to corroborate this view. Another theory, which is now generally adopted, refers the origin of interior heat, or at least so much of it as is necessary to produce volcanic eruptions and earthquakes, to the friction of the rocks resulting from the subsidence or upheaval of portions of the earth's solid crust.

CHAPTER VIII.

ON VOLCANIC PHENOMENA AND DISTRIBUTION OF VOLCANOES.

54. **Volcanoes—Active—Dormant.**—Before proceeding to consider the mode and causes of volcanic action, let us in the first place define exactly what is meant by the term 'volcano,' and, secondly, point out very briefly its general structure and mode of formation. Sir Charles Lyell defines a volcano as a 'more or less perfectly conical hill or mountain formed by the successive accumulations of ejected matter in a state of incandescence or high heat, and having one or more channels of communication with the interior of the earth by which the ejections are effected.' This must be regarded as a definition of the term in a rather limited sense, and is, in fact, simply an alliteration of the popular synonym for volcano—that is, a burning mountain. But the appellation volcano is not, either in a strictly geographical or geological sense, restricted to those cones whose eruptions are attended with an emission of flame, as in some volcanic eruptions there is no appearance of fire, only water or steam being ejected. But as the latter are evidently due to the same igneous or volcanic agency, they are appropriately designated by the same name. Volcanoes, then, are those parts of the earth's surface, whether considerably elevated or scarcely at all, at

which heated solid, liquid, or gaseous matters are thrown out from the interior of the earth to the surface. Volcanoes generally are of some elevation, and usually of a more or less conical form, owing to the successive accumulations of ejected matters from a central crater. Elevation, however, does not alter the character of volcanoes, slightly elevated cones being equally volcanic with those of great height. The cup-like top of a volcano is called the crater, and is the external termination of the funnel or neck of the volcano, through which the lava and other matters are ejected during an eruption, or when the volcano is *active*. When it is not active, the pipe or funnel communicating with the interior is often closed up with igneous matters, which may be so firmly fixed as in all appearance to preclude further eruptions. When this is the case, and no eruptions have taken place within the historic period, the volcanic forces being either too feeble to produce another eruption, or it may be having altogether subsided in that particular region, the volcano is said to be *dormant* or *extinct* (the latter term can scarcely be applied with any degree of certainty to any volcano; the term dormant therefore is preferable). But the distinction between active and dormant volcanoes, although in many cases seemingly confirmed by the records of ages, is yet liable at any moment to be reversed, and a volcano long thought dormant, if not extinct, may suddenly assume a state of violent activity; and, on the other hand, a violent eruption taking place at a certain point may never be repeated in that particular spot, the tension being relieved in other directions. We may class active volcanoes as periodical and continual, the former being in a state of activity at uncertain intervals of time, the latter including those always in action. The former class generally comprises volcanoes of moderate or considerable elevations; the latter, which are few in number, are but slightly elevated.

55. **Structure and Formation of Volcanoes.**—A regularly-formed volcano is of a more or less conical shape, with a broad base, terminating upwards, not like other mountains in a peak, etc., but in a cup-like crater depressed inwards to a central cavity or funnel communicating with the interior of the earth. A volcanic cone, according to Lyell and others, is formed of successive accumulations of lava, stones, ashes, and other matters thrown out on the surface at the point of ejection, the more solid substances cooling in masses close round the crater, the more liquid lava flowing down the declivities for considerable distances before being finally consolidated. Eruption after eruption adds new layers of lava, etc.; and as the harder substances are massed together round the crater, while the softer lavas, flowing downwards, spread over wide areas, the elevation is greater at this part than at any other, so that the volcano ultimately assumes a more or less conical shape, and often attains a great elevation. According to this view, an ideal section of a regularly-formed volcano may be thus roughly represented. Describe a broad-based isosceles triangle ABC, and from the vertex B let fall a perpendicular BD on AC. Cut off BF and BE from AB and BC respectively, and draw EG, FG, meeting BD in G. Join ED, FD. Rub off the lines EB, BF, and BG, and from ED and FD draw parallels to EG and FG, meeting in the perpendicular GD. Then from ED and FC draw other lines parallel to EA and FC. These parallels show that the beds immediately surrounding the crater and funnel dip per-

ceptibly inwards to the perpendicular GD, which shows the funnel or neck of the volcano, while

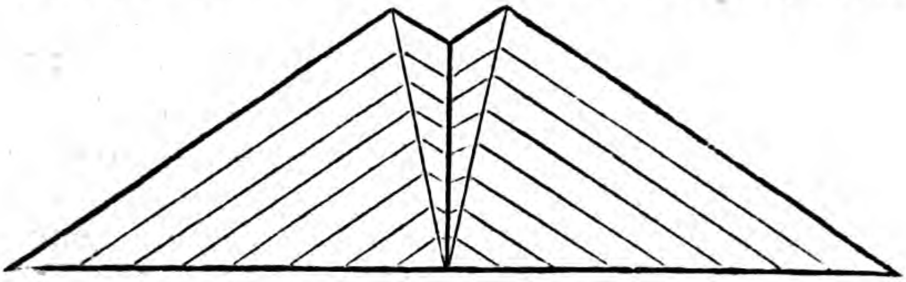


Fig. 11. Ideal section of a volcanic cone, drawn as directed.

away from ED and FD they dip slantingly outwards. If other smaller triangles, similarly drawn, be so placed as to cover part of the central triangle, and connected by parallels from their respective perpendiculars, they will show what are termed lateral craters. The foregoing remarks apply in their entirety only to regularly-formed conical volcanoes. These, however, are rarely met with in nature, the volcanic force always working in the line of least resistance; the matters are ejected sometimes through the sides as well as the top of the cone, but generally the former. Humboldt, Beaumont, and others, however, assert that a volcanic cone is not formed of successive layers of erupted matters, but is due to a sudden bubble-shaped expansion of the earth's crust; this, meeting with no resistance at the surface, swells upwards, forming an elevated cone, which, bursting at the top, gives rise to the hollow, cup-like form of the crater. Of these two theories, 'craters of eruption' and 'craters of elevation,' the former is now generally adopted—that is, that volcanic cones have been formed by the successive accumulations of erupted matters, and not by a sudden peculiar upheaval ot the earth's crust. But in reality these two views may be and are both correct, some cones being evidently mainly formed by a peculiar upheaval of the overlying strata, while others, again, appear to have been formed by successive accumulations of erupted matters. In both cases the results are the same — upheaval and eruption being, in fact, synonymous, expressing the perceptible effects of one and the same force.

56. **Mode of Volcanic Action.** — The general phenomena which accompany volcanic eruptions may be thus briefly summarized. Earthquakes more or less violent are usually the immediate precursors of volcanic eruptions, and, affecting both sea and land, produce (by displacement of the ocean floor) great agitation in the former, the waters rising and sinking alternately; while on land their effect is seen in the trembling or vibration, or sudden upheaval or depression of the surface, thus causing vast destruction of life and property. Springs and wells in the neighbourhood of the volcano, and even at great distances from it, either become dry and filled with carbonic acid or other gases, or discharge muddy, impure water. Just before the eruption takes place, tremendous explosions and deep rumbling noises are often heard. All this time steam, sulphuretted hydrogen, and other gases are given off from the fissures in the crater or slopes of the mountains, or ashes may be ejected. At length the eruption commences with deafening explosions, accompanied by the emission of vast quantities of steam and various gases, which rise in a smoky-looking lurid column frequently to a height of 1000 feet, dilating above into broad, massive clouds, from which showers of rain are often discharged. Showers of red-hot stones or ashes, fragments of rocks, large blocks, sometimes weighing many tons, and white-hot

molten stones or lava now burst forth in quick and apparently interminable succession from the central or, as is more often the case, from a lateral crater. The existing crater, if not entirely destroyed and a new one formed, is generally much altered and reduced, the incoherent materials of which it is composed being suddenly displaced by the violence of the eruption and shot upwards with great force. Immense quantities of ashes are often ejected into the higher regions of the air, and are transported by the prevailing winds to considerable and often great distances, obscuring the sun at noon, and covering the ground to depths of many feet at 20, 30, or more miles distant, and sometimes burying whole cities. The molten lava bursting through the top, or more generally the sides of the mountain, streams down the slopes over wide areas, often overwhelming entire towns and villages, and causing great loss of life. As the lava flows on, its upper surface first cools and hardens, and, contracting as it cools, gives rise to great cracks or fissures, through which the still molten lava in the interior may be seen still flowing underneath. Steam and various gases are emitted from the cracks of the crater and the lava, while forked lightning is often seen, produced probably by the intense friction in the air to which the ejected stones and rocks are subject; the falling masses meeting with others shot upwards, are thus reduced to small fragments (*lapilli*) and fine dust or ashes (*ceneri*). Such are the general phenomena accompanying an eruption of a volcano, properly so called, *i.e.* attended with emission of smoke and flame. A few volcanoes of this class are always active, but not to any great extent; and by far the greater number of the fiery volcanoes, if we may say so, are active at intervals. Some volcanic eruptions, unlike these, are unaccompanied with any appearance of fire, torrents of hot water and mud only being thrown out. These are as destructive to life and property as the former, if not more so. They are said to represent the declining stage of volcanic activity. Other examples of what may be termed subdued volcanic activity are furnished in *fumaroles*, or emission of jets of steam or other gases during and after the eruption. If large quantities of sulphur be emitted, the jets form a *solfatara*. Examples of these will be given at the end of this chapter.

57. **Causes of Volcanic Action.**—In order to furnish an intelligent explanation of the *modus operandi* of volcanic action, it was necessary to theorize as to its probable causes or origin. Accordingly the so-called *mechanical* theory was advanced, referring volcanic phenomena to the original interior heat of the earth; that is, as we have already explained, the earth was supposed to have been originally in a state of fusion, and having in its rotation assumed a state of equilibrium as a sphere, gradually radiated its heat into the surrounding space, the surface cooling first, and, ultimately consolidated, forming a rigid rocky crust enveloping an interior highly-incandescent or molten mass. This theory, as we remarked before, is apparently confirmed by the increase in temperature from the stratum of invariable temperature downwards, and consequently, at the observed rate of increase in mines, etc., it was concluded that at a depth of about 40 miles, or the 200th part of the earth's diameter, all known substances would be in a state of fusion. And this view is further supported by the universal occurrence of volcanic action, and the intimate connection which undoubtedly exists between

centres of volcanic action. It is therefore contended that volcanic and other igneous phenomena can only be satisfactorily explained by supposing that the rocky crust encloses a molten sphere, and that, as the interior heat is still radiated into space, the unequal contraction of the earth's crust consequent upon cooling forces portions of the molten matters through fissures in the overlying strata to the surface, thus giving rise to volcanic eruptions. The eruptive forces primarily caused by the unequal contraction of the earth's crust are made still more powerful by vast quantities of steam and other gases generated by the vaporization of the water, which, gradually percolating through the fissures of the solid crust, at length come in contact with the interior heated mass. That water does reach strata of great heat is clearly proved by the existence of hot springs in nearly all parts of the earth, and the almost continual emission of steam in many places, often accompanied by emission of other gases, chiefly carbonic acid and sulphuretted hydrogen. The introduction of water, then, into contact with the interior heated mass gives rise to a series of mutual decompositions, by which means immense quantities of various gases and vapours are released; and if, on expanding, they find no vent, they explode with great force, producing violent vibratory agitation of the earth's surface, or earthquakes. A still further addition of force causes the excited interior matters to break through the crust to the surface, successive eruptions at the same place eventually forming a volcanic cone.

The impossibility, however, of such conditions as are either implied or distinctly stated as the basis of this 'mechanical theory,' is evident from many considerations, of which the most directly conclusive, perhaps, is the fact that, according to this hypothesis, the solid rocky crust is represented as being no more than about 40 miles in thickness. Now the earth's diameter is 8000 miles or thereabouts, and therefore the proportion of the solid crust to the earth's diameter would be as 1 is to 200—that is, the solid crust of the globe is only a 200th part of the earth's diameter, a proportion of crust so minute in comparison with the magnitude of the earth that the disparity between the vastness of the interior molten mass and its perceptible effects on the surface renders the acceptation of this theory in its entirety more a matter of blind faith than a well-founded scientific belief. Again, as Sir W. Thomson well remarked, in his address to the British Association at Glasgow, this theory

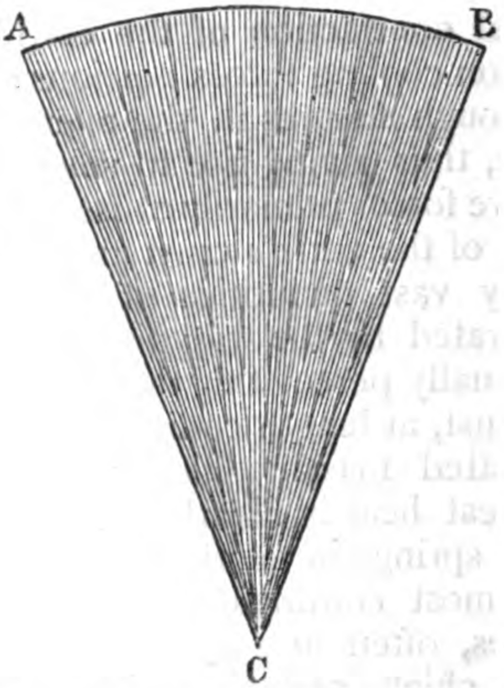


Fig. 12. Showing the supposed proportional thickness of the solid crust AB of the globe; C, the centre of the earth; AC or BC, the radius. The shaded part shows the proportional area of the section supposed to be fluid or molten.

evidently violates established physical laws; for if a rigid crust be supposed to enclose a fluid interior, the equilibrium of such a body would not be stable, and nothing could possibly prevent the denser solid substances of which the crust is composed from sinking below the liquid mass of the interior. But supposing this to be the case, and the rigidity of the crust to be such that the interior molten mass is on the whole safely confined, volcanoes which are in direct communication with the interior of the earth would present some indications of a tidal movement in this ocean of fire in the periodical rising and sinking of the lava within the crater. But no such thing occurs, and this is still further confirmed by the fact that volcanic eruptions are not periodical—that is, they do not recur at regular intervals of time. Again, it is contended that the phenomena of the precession of the equinoxes could not possibly be what they are unless the earth were solid to a vast thickness, if not entirely so. The only satisfactory way of explaining and reconciling many physical and astronomical phenomena is to assume the earth to be solid as a whole, but that cavities of immense extent exist at uncertain depths, filled with molten matters, and perhaps intimately connected with each other by subterranean passages. Of course we cannot definitely say whether these cavities extend to the very centre of the earth or not, but from many calculations it is probable that the great foci of volcanic action are only a few miles below the surface, for if the ejected substances had to traverse any considerable distances, they could not retain their red heat. As to the *chemical* theory advocated by the late Sir H. Davy and others, we shall only offer a few brief explanatory remarks. According to this theory, it was supposed that the strata at some depth below the surface were composed of alkalaginous metals in a pure state; and the principal volcanic product, lava, is, as is well known, composed of compounds of potassium, sodium, etc. These substances, when water gains access to them, are decomposed, the decomposition being attended with an evolution of intense heat sufficient to fuse rocks found at that depth, to convert water into steam, and in various ways, as by repeated mutual decompositions, to release vast quantities of carbonic acid, sulphuretted hydrogen, and other gases. These in expanding or exploding agitate the overlying strata, thus causing earthquakes, or, gaining additional strength, even burst through the various strata to the surface, carrying with them masses of molten matters, thus producing a volcanic eruption.

58. **Volcanic Products.**—As we stated before, lava, ashes, steam, and various gases (chiefly carbonic acid, oxygen, hydrogen, nitrogen, and carburetted hydrogen) are emitted during an eruption. *Carbonic acid* appears in large quantities only when the eruption is nearly over, and then forms nearly 90 per cent. of the gases emitted. In the earlier stages *hydrogen* preponderates, being about 30 per cent. of the total quantity emitted; but as the amount of carbonic acid increases, the quantity of hydrogen diminishes, and at length is *nil.* Besides these gases, many other substances are given off from the fumaroles or smoking vents of the crater and lava streams. These consist of exhalations of *soda*, *potash*, *sulphur*, etc., in variable quantities. A remarkable phenomenon has been recently observed as regards the emission of volatile elements during an eruption, viz. that there is a constant and certain relation between the nature

of these products and the intensity of the eruption. Eruptions of great intensity emit chloride of sodium principally, and also salts of soda and potash; those of less intensity, chloride of iron and hydrochloric acid; others of still less intensity, ammonia, salts, and sulphuric acid; while those of slight or feeble intensity emit steam, carbonic acid, and other inflammable gases. *Steam*, as we have said, is nearly always given off during an eruption, and, being almost immediately condensed, falls in torrents of rain on the surface of the volcano, carrying with it the finer ash, forming immense streams of hot mud, which, flowing down the slopes of the volcano more or less rapidly according to the steepness of the descent, spreads over wide areas, often overwhelming whole towns and villages. Immense quantities of *volcanic ash*, or the finely-triturated fragments of the ejected lava,—in fact, cooled lava 'spray,'—are thrown out of the crater, the coarser ashes being often carried to a distance of 50 miles and upwards, while the finer dust shot into the higher regions of the air is transported by wind currents as far as 600 or 800 miles from the volcano. But the principal volcanic product is *lava*, which includes all those substances thrown out from the crater of a volcano in a molten state. The quantity of lava ejected differs greatly, sometimes only enough to fill the cavity around the vent, at other times in such quantities as to cover areas of 50 or 60 miles long by 10, 15, or even 20 miles broad. Lava issues from the crater in a highly-incandescent state; but as it flows down the slope, its surface soon cools by exposure to the atmosphere, and as it gradually hardens, becomes seamed with cracks, through which the molten lava may be seen still flowing. The hardened surface thickens but slowly, and the internal mass retains its heat and fluidity for a long time after the surface is quite cold and firm. Geologically considered, all those rocks which have been ejected from a volcano in a molten state are called lava, which, cooling more or less rapidly, results in the formation of rocks having a more or less compact texture. There are several varieties of lava, of which we will briefly note the principal. *Basalt* is the hardest and most compact igneous rock, somewhat dark-coloured, and composed of felspar, augite, and iron, often containing olivine. The columnar structure of basalts, as in the Giant's Causeway of the north-east coast of Ireland, Fingal's Cave in the island of Staffa, is supposed to be mainly due to the contraction of the lava on cooling. *Obsidian* or volcanic glass is, as its name implies, of a glassy texture,—so much so, indeed, that it is scarcely distinguishable from common glass. *Pumice* is a light porous rock, and is, in fact, but a variety of the preceding rendered porous by the bursting of the bubbles of gas confined in the mass while in a state of fusion. *Pearl-stones* are more compact than pumice-stones, but less so than obsidians. The light, cindery stones found on the surface of the lava streams and elsewhere, as well as the heavier vitreous substances ejected from the crater, are all termed *scoriæ*. If the stony fragments are comparatively large, they are called *volcanic bombs*, while the smaller pieces are termed *lapilli*. *Volcanic sand* consists of the coarser, and *volcanic dust* of the finer comminuted fragments of lava. Commercially considered, many volcanic products are of great importance. Lavas are used for building and other purposes. Hundreds of tons of pumice are annually used as polishing stones. *Sulphur* is almost entirely obtained from volcanic districts, upwards of 80,000 tons being annually exported from Sicily alone. Immense quantities of *borax* are derived from hot springs, while many precious stones, such as *agates*, *chalcedony*, *olivine*, etc., are found embedded in the older lava rocks.

59. **Distribution of Volcanoes.**—A remarkable fact in connection with the present distribution of volcanoes on the globe is that fully two-thirds of the active volcanoes are situated on islands, and that the remaining third, with few exceptions, are ranged along the margins of continents, suggesting if not proving the necessity of water in producing volcanic action. This fact has been adduced in support of both the theories of volcanic action which we adverted to in the last paragraph. According to the 'mechanical' theory, water finding its way to the interior heat is converted into steam, the expansive force of which is held to be the principal cause of volcanic phenomena. As regards the 'chemical' theory, which is, as we said, based upon the fact that water is decomposed by the alkalaginous metals in a pure state, and, further, that this decomposition is attended with the evolution of great heat, the proximity of water to the lines of volcanic action is a *sine qua non.* To these views it is objected that many volcanoes are at great distances from any considerable bodies of water, and consequently that it would be necessary to assume the existence of fissures of immense extent. The Thian Shan mountains in Central Asia are put forward as examples. But recent research has shown that these points are simply mud and vapour vents, and therefore represent the last stage of volcanic activity; and further, inland volcanoes are the exception and

not the rule. Volcanoes, then, occur mostly in more or less well-defined lines, either on or near the sea-coast, or in chains of islands. Some geologists regard the continuity of these lines as evidence of simultaneous volcanic action in the districts through which they pass; but it is more probable that these lines indicate successive series of eruptions in the same general directions. The most continuous line of volcanic activity is that nearly encircling the Pacific Ocean. Commencing at the south in the adjoining Antarctic Ocean, we have Mount Erebus rising to a height of 12,000 feet in Graham's Land. Proceeding northwards, we come to the southern extremity of South America, the highest volcano of Tierra del Fuego being more than 7000 feet. Then follow the Patagonian volcanoes, leading northwards into the Andes, which, from 43° south latitude to 2° north latitude, exhibit an enormous number of active volcanoes, there being more than 30 peaks between 43° and 30° south latitude, of which the highest is Aconcagua, the loftiest mountain in the New World. Only one active volcano has been observed in Peru, about 8 in Bolivia, and 20 around Quito, nearly all above 14,000 feet in height. Among the latter we have, near the town of Quito, Cotopaxi, 19,000 feet high, Chimborazo, Antisana, and Pichincha. Farther north we have two lines of volcanoes in Central America, one passing through the western islands of the West Indies, in which there are two volcanoes; the other passes through Guatemala and Mexico, which possess over 30 active volcanoes, 5 of which traverse the country at right angles to the main range. The principal cones are Cosequina in Guatemala, and Tuxtla, Orizaba, Popocatepepl, Jorullo, and Colima, which traverse the plain of Malpais from east to west. Of these, Jorullo was formed in one night in the year 1759. North of Mexico, in the Californian peninsula, and on the north-west coast of North America, there are 4 or 5 active volcanoes, the line terminating in Mount St. Elias in Alaska. The latter is connected with those of the north-eastern part of Asia by the Aleutian Islands, of which about 20 are volcanic. Passing on to Kamtchatka, which contains about 20 volcanoes, we find some cones of great height, that of Klutchen rising to a height of 15,000 feet. Continuing southwards, we pass the Kurile Islands, of which about 12 are volcanic, and the Japan Islands, which contain over 25 active cones; passing by Loo Choo and Formosa to the Philippines, in which there are about 20 volcanoes, and thence to the Celebes, where it divides, branching westerly to Sumbawa, Java, Sumatra, to Barren Island in the Bay of Bengal, while the other branch is continued in a south-easterly direction through New Guinea, New Hebrides, and New Zealand to Victoria Land, thus completing nearly a circle round the Pacific. Java is the most intensely volcanic district in the world, containing about 50 active or dormant volcanoes. Another less continuous line may be traced from the Thian Shan Mountains, on the borders of China, westwards across the Asiatic Continent to the neighbourhood of the Persian Gulf and the Caspian Sea, on the southern shores of which the smoking cone of Demavend rises to a height of 18,000 feet. Then still west by the Armenian and Caucasian Mountains, and through the Catakecaumene of Asia, we reach the Mediterranean. Here we have the volcanic islands of Melos and Santorin in the

Grecian Archipelago, Vesuvius near Naples, Etna in Sicily, the Lipari Islands and Stromboli, while in central France the mountains of Auvergne, etc. are extinct volcanoes. Scattered over the Pacific are many volcanic islands, viz. New Britain, Norfolk Island, Friendly Isles, the Society, Ladrone, and Sandwich Islands. In the latter is the well-known volcano Mauna Loa, nearly 14,000 feet high, one of its craters, Kilanea, being the largest in the world. While the shores of the Pacific are thus decidedly volcanic, the shores of the Atlantic are the reverse, but not so the islands. Among these we have the Canaries, Azores, Iceland, and the West Indies. Africa, again, is singularly free from volcanic action, slight traces of which are only found in the Atlas ranges, and in the region near the Red Sea. In the next paragraph we propose to note very briefly a few of the most remarkable volcanoes and eruptions.

60. **Notes on the Principal Volcanoes.**— *Vesuvius*, near Naples, in Southern Italy. The first recorded eruption took place in the year 79, when two cities, Herculaneum and Pompeii, situated about 4 and 6 miles respectively from the crater, were buried, the first by streams of lava, the second by showers of ashes. Both have been partially excavated. The ashes thrown out in this eruption were carried as far as Egypt and Syria. Again very destructive eruptions took place in 1631 and 1632. In July 1794 another terrible eruption occurred, the lava stream destroying the town of Torre del Greco, and was altogether over 4 miles long. During the present century Vesuvius has been in action several times; by that of 1822 the accumulated mass around the crater was thrown off, 800 feet of the old cone being carried away. Eruptions also took place in

1828, 1831, 1832, and another in April 1872, which was observed and minutely described by Professor Palmieri.—*Etna*, in Sicily. About 60 recorded eruptions. Its cone has repeatedly fallen in, and again and again been reproduced. It is 11,000 feet high, and just before the great Calabrian earthquake in 1783 it was observed that Etna and Stromboli smoked less than usual.—*Skaptar Jokul*, in Iceland. A most violent eruption took place in 1783. The liquid lava spread out for 20 or 30 miles; clouds of ashes were carried many hundreds of miles, some falling even on the Orkneys. The eruption lasted 2 years, during which time more than one-sixth of the inhabitants of the island perished. Sir C. Lyell computes the ejected mass to be equal to if not greater than the bulk of Mont Blanc.—*Mauna Loa*, in the Sandwich Islands, is 13,700 feet high, and has two craters; the one on its side, about 8000 feet below the summit, is 7 miles round, and nearly 1000 feet deep.—*Cotopaxi*, in the Andes, is a perfect cone shooting up to a height of nearly 20,000 feet, and therefore above the line of perpetual congelation. The column of ejected matters during an eruption is supposed to attain a height of over 3000 feet.—*Jorullo*, 1600 feet in height, is the loftiest of a series of 5 volcanoes which were thrown up on the plain of Malpais in Mexico in the year 1759.—*Cosequina*, in Guatemala, during an eruption in 1835, ejected ashes which were carried as far as Kingston in Jamaica, 700 miles distant.—*Tomboro*, in the island of Sumbawa, in 1815 threw out ashes which covered the surrounding country to a distance of 300 miles.—*Mount Erebus*, in Graham's Land, in latitude 85° south, is 12,400 feet high, and was seen in action in 1841 by Sir James Ross, who calculated the column of ashes ejected to have a height of 2000 feet.

CHAPTER IX.

ON EARTHQUAKES.

61. **Earthquakes.**—Earthquakes, as the term implies, are literally 'quakings' of the earth, and are the effect of more or less violent subterranean commotions, which, acting on the overlying strata, cause a vibratory or heaving motion of the surface, often scarcely felt, but sometimes the ground splits in various directions, producing chasms varying in width from a few feet to many yards, and often miles in length, which not unfrequently engulf whole towns. At other times the ground has a wave-like, rocking motion to and fro, or is suddenly upheaved or depressed, often causing vast destruction of life and property. According to the manner in which they act, earthquakes have been distinguished as *undulatory*, *perpendicular*, or *rotatory*. The first consist of wave-like motions or undulations of the solid crust, and are by far the most common, being felt more or less in nearly all parts of the earth, and are not unusual in Great Britain. Although of more frequent occurrence, they are the least destructive. In those termed *perpendicular*, the ground is suddenly upheaved and then as suddenly depressed, the amount of depression and upheaval being sometimes equal, in which case no permanent alteration takes place in the level of the land;

the general result, however, being a greater degree of upheaval than depression, consequently there is a permanent elevation of the land. 'Perpendicular' earthquakes are not of such frequent occurrence as the 'undulatory,' but are much more destructive. Sometimes, but fortunately very rarely, both these movements—that is, the undulatory and perpendicular (or a wave-like motion of the ground to and fro, simultaneously with sudden upheaval and depression)—are combined, and the result is that most awful and destructive form of earthquake known as the *rotatory* or *horizontal.*

62. **Cause of Earthquakes.** — Formerly earthquakes were defined to be the 'reaction of the liquid nucleus against the outer crust.' We have seen, however, that the theory of internal fluidity cannot be maintained, and therefore this definition must be considerably modified to meet modern views as to the cause or causes of earthquakes. Earthquakes and volcanoes are closely associated, and most probably depend on the same causes. The causes of volcanic action have been referred to at some length in the preceding chapter, and therefore we shall here only touch briefly upon the principal points. According to our theory, although the earth as a whole is solid throughout its entire extent, yet there are vast subterranean cavities filled with molten matters at various depths below the surface, in direct communication with the surface by means of the volcanic vents. Now water, constantly sinking down through cracks or fissures in the superficial strata of the ocean bed or of the land, ultimately gains access to these heated caverns, and is immediately converted into steam, which, exposed to such intense heat, expands more and more, and, being

subject to such great pressure, explodes violently; the concussions produced by the explosion being imparted to the superficial strata, constituting what are known as earthquakes. Some suggest that earthquakes may be caused by the sudden precipitation of large masses of rocks into the molten subterranean seas, the effect of the sudden displacement or concussion acting on the surface strata. Others suggest that earthquakes are due to the sudden generation of immense quantities of steam, as when large masses of water are suddenly precipitated into the molten cavities by the shrinking or cracking of the solid crust. In all the theories which are advanced in explanation of the phenomena of earthquakes, we observe that some prominence is given to the action of steam, to the expansive force of which physicists now generally refer volcanic phenomena and earthquakes. The difference between these two forms of one and the same force is this: in volcanoes, the agitated molten matters and heated vapours find a vent by which they can escape to the surface; while in earthquakes the disturbed matters, finding no vent by which to relieve the overwhelming pressure, and consequently increased expansive power, explode again and again, shaking and sometimes pushing up, or even rending, the superincumbent strata.

63. **Mode of Action.**—The disturbing force generally emanates from one point or centre, situate some distance below the surface. The shocks radiating from this point affect large areas, and, as a general rule, the deeper the seat of the disturbing force or focus, the wider is the area influenced. The shock, however, is not propagated on the surface in a horizontal direction (like the

concentric waves formed on the surface of a pond or lake when a stone is dropped), but perpendicularly at that point on the surface right above the centre (this point is known as the *seismic vertical*), and more and more obliquely as we recede from the centre. If, therefore, the seismic vertical be found, and its distance from a certain *co-seismic point* be accurately measured, and also the direction in which the wave emerged at these points, we may determine roughly the depth of the focus or centre of disturbance. Knowing, then, the direction of the emerging wave at each of the two points specified, if we imagine two lines to be produced inwards from these points in these directions, they will ultimately meet, and the point where they meet is the focus or centre; so that here we have a right-angled triangle, of which the base is the line on the surface between the two points. Given, then, the angles of the triangle and the length of the base, the depth of the focus may be easily ascertained. Mr. Mallett thus concluded that the focus of the great Calabrian earthquake in 1857 was probably at a depth of only 7 or 8 miles. But when we take into consideration the heterogeneous character of the materials of which the crust of the earth is composed, we see at once that the shock cannot possibly be transmitted in a uniform direction, and therefore all such calculations must at best be taken as mere approximations. From these and other researches, Mr. Mallett has been led to conclude that the foci of earthquakes generally are at no greater depth than 30 miles.

Immediately before an earthquake, an unnatural sultriness in the air and a sudden fall of the barometer have been observed; but generally the most violent earthquakes come on suddenly, without giving the least warning. As we have said before, earthquakes present various phases, the shock, in most cases, imparting an undulatory, wave-like motion to the ground. More violent shocks produce a sudden upheaval at or near the centre of disturbance; while the most violent and destructive earthquakes consist of simultaneous upheaval and undulatory movements, producing a complicated verticose or whirling motion of the surface crust.

64. **Results of Earthquakes.**—We have already noticed the general effects of earthquake shocks on land, from slight tremors hardly felt, to violent convulsions of the upper strata, when the ground rocks to and fro, or is suddenly lifted up or depressed, overthrowing buildings and reducing whole towns to ruins, detaching immense masses of rocks from the sides of mountains, and hurling them to the intervening valleys, often barring river courses, thus forming lakes; or the ground splits in various directions, and towns and villages are partly or entirely engulfed in the yawning chasms, which sometimes close again, thus obliterating every mark of their existence. The awfulness of earthquakes is intensified by the suddenness of their occurrence. Thus the great Lisbon earthquake came on without the least warning. Prior to a violent volcanic eruption, there are nearly always some premonitory signs of its approach, and consequently the inhabitants of the threatened districts are sometimes able to escape in time to a safe distance; but, as we have said, earthquakes come on so suddenly, and influence such wide areas, that the escape of the inhabitants of the central districts of disturbance is almost impossible, and sometimes the very spot hurried to for safety proves their destruction:

witness the flight of a large number of people at Lisbon to the new quay when the shock was first felt. The quay soon after sank, and all on it perished. Sometimes the level of the disturbed district is permanently affected, being either elevated or depressed (generally the former). Usually the elevation or upheaval of the land is only temporary, being soon after depressed to its former level. The effects of earthquakes on any considerable bodies of water are also very striking—water, from its homogeneity, being much more readily affected than the heterogeneous solid crust. When the concussion takes place under the bed of the ocean, an ocean wave is formed by the vertical displacement of the ocean floor. The ocean wave travels towards the land at a rate proportional to the intensity of the shock; but as the earthquake wave is propagated much more quickly through the solid crust, the consequence is that the earth or ground wave reaches the land first; and hence the sea seems at first to retire, but is soon after checked by the onward advance of the great ocean wave, sometimes 50 or 60 feet high, which rushes on the land in an unbroken line of great length, flooding the whole coast to a considerable distance inland, and in retiring completes the havoc its advance had made. Sometimes, when no shocks or tremblings are felt on the land, the waters of lakes and ponds are seen to be greatly agitated, great waves dashing on shore even when there is no wind or any other apparent cause. The disturbance, therefore, must be due to earthquake shocks, too far distant to be perceptibly transmitted through the solid strata to the surface.

65. **Distribution of Earthquakes.**—Earthquake areas and volcanic districts may be said, generally

speaking, to be coincident; but if we include all those places at which the least intense forms of earthquakes are felt, then the former are much more extensive than the latter. Those parts of the earth visited by earthquakes are called *earthquake bands*, and, as we have said, are generally coincident with the lines and centres of volcanic action. In Europe an earthquake band extends through Spain, France, Holland, the British Isles, to Iceland. No fewer than 116 earthquake shocks have been recently recorded in England, 31 of which were observed along the south coast, 14 in Yorkshire and Derbyshire, and 30 in Wales. During the same period 139 shocks were observed in Scotland, 85 of which took place at or near Comrie in Perthshire. Another very intense area extends from Bengal in India, through South-Western Asia and the Mediterranean, to the Azores, while another strikes northwards from the Himalayas in Northern India to the Thian Shan and Altai Mountains in Central Asia. Africa is singularly free from both volcanic action and earthquake shocks, the latter being only slightly felt occasionally in Cape Colony, Morocco, and Egypt. The line of islands encompassing the western portion of the Pacific Ocean are quite the reverse, being intensely volcanic, with the singular exception of Australia. The whole western coast of America from Alaska to Cape Horn is also subject to earthquakes, as also portions of the east coast of North America from the West Indies and the Alleghanies as far north as Nova Scotia. The most intense development of seismic activity, however, in the New World is in Central America and the West Indies and the Chilian coast.

66. **Remarkable Earthquakes.**—Pliny and other

ancient writers mention many remarkable earthquakes. One of the most violent kind is said to have taken place in Asia in the reign of Tiberius Cæsar, when twelve cities were reduced to ruins in one night. In 1583 the town of St. Euphemia in Calabria was engulfed, with all its inhabitants, and its site occupied by a lake. In 1600 a violent earthquake occurred at Arequipa in Peru. In 1628, off St. Michael, one of the Azores, an island was thrown up in water 160 fathoms deep, which in 15 days measured 9 miles long by 4 broad, and 360 feet above the sea level. In that of the 11th of January 1693, in Sicily, no less than 60,000 persons perished. Callao, the port of Lima in Peru, was visited by a terrible earthquake on the 28th of October 1746, characterised by a sudden irruption of the sea, which swept away the greater part of the town. But the most terrible earthquake probably ever experienced was that of Lisbon, which occurred on the 1st of November 1755. We append Professor Johnston's succinct account of this awful catastrophe. The great Calabrian earthquake commenced on the 5th of February 1783, and the shocks were felt over an area of 500 miles; and between the 38th and 39th degrees north latitude alone, over 200 towns and villages were destroyed. Besides the casualties consequent on the sudden falling of buildings, extensive landslips also took place, burying villages and their inhabitants. Altogether, it is computed that this earthquake proved fatal to 100,000 persons. In 1822 a destructive earthquake was experienced on the coast of Chili, by which great damage was done to Valparaiso and other seaports, and ultimately resulted in the permanent elevation of a portion of the Chilian coast 3 or 4 feet above its former level. In 1842, 10,000 of the inhabitants of Hayti perished in an earthquake. The most violent earthquake, or rather series of earthquakes, of recent occurrence took place in 1868 on the west coast of America. Their effects were felt more or less for more than 3000 miles along the coast and to a considerable distance inland, some of the towns at great elevations in the Andes even being greatly damaged. At Callao three shocks were felt, while at Arequipa houses and other buildings fell, and many persons were killed. At Iquique and Arica the sea at first apparently retired, then returned in a huge wave 50 or 60 feet high, which swept vessels from their moorings and carried them far inland. The ocean waves produced by this disturbance extended even to New Zealand, Japan, California, and the Sandwich Islands. No earthquake probably ever devastated such a wide area as this. Thousands of persons were killed by falling houses, etc., and most likely a much greater number were drowned by the inrush of the sea.

67. **Earthquake of Lisbon, 1755.** — Professor Johnston gives the following graphic account of this catastrophe:—'Suddenly a sound like subterranean thunder was heard; this was immediately succeeded by a violent shock, which demolished the greater part of the city, and in the course of *six minutes* 60,000 persons perished. The movement of the earthquake was undulatory, and it was calculated that it travelled at the rate of 20 miles a minute. A space more than four times the extent of Europe, or nearly one-twelfth of the superficial area of the globe, was shaken by this earthquake, which had for the axis of its shock a line extending from Mogadore, on the coast of Morocco, along the west coast of Portugal, to Cork, in the south of Ireland. From Lisbon, the central

point, the line of devastation extended northwards to Oporto, and southwards to Ayamonte, where the Guadiana falls into the Bay of Cadiz. Within this entire space, the sea, fearfully agitated by the concussion of its bed, caused the greatest destruction. At Cadiz a wave 60 feet high rolled over the land, and at Lisbon the sea rose 50 feet above its usual level. At Kinsale, in Ireland, the sea rolled into the harbour, and overflowed the market-place; and at Funchal, in Madeira, it rose 15 feet above the highest water-mark. The space within which this earthquake was observed on land extended in an elliptical form from the island of Madeira to Abo, in Finland, and from Scotland to Sardinia. In Scotland, the water in Loch Lomond, Loch Katrine, Loch Long, and Loch Ness was observed to rise and fall repeatedly to an extent of 2 or 3 feet; and this movement of the surface of the water was especially observable in the lakes of Germany, Switzerland, and France, as well as in those of Scandinavia. The agitation of the waves of the sea extended even as far as the West Indies, where the islands of Antigua, Barbadoes, Guadaloupe, and Martinique were overflowed, and a ship forty leagues to the west of St. Vincent suffered a violent shock. At the same time an unusual movement was observed on the surface of Lake Ontario, in North America. The concussion assumed the form of an ellipse, of which the largest diameter, characterised by the destruction which was produced in its course, extended over 300 miles. The space over which the shock was perceptibly felt extended to 2700 miles; and the area of vibration, or the greatest extent over which water was observed to oscillate at the surface, extended to about 4000 miles!'

CHAPTER X.

ON THE SLOW UPHEAVALS AND SUBSIDENCES OF THE EARTH'S CRUST.

68. **General Results of the Forces acting upon the Earth's Crust.**—Before proceeding to consider in detail those slow movements of upheaval and depression to which the earth's crust is subject, let us notice very briefly the general results of the various forces which directly or indirectly act upon the earth's crust. The results of some of these forces appear chiefly on the surface, and may therefore be termed *external forces;* while others, again, although their action is perceptible to us only by their effect on the surface strata, are yet deeply seated in the interior of the earth, and may therefore be appropriately termed *internal forces.* Of the external forces, the most general in its action, although probably not the most effective as regards results, is the air, which acts directly by its wind currents, and indirectly by the chemical action of its constituent gases, by frost, desiccation, or drought, and by diffusing light, heat, and moisture. The mechanical action of winds is strikingly shown in the continual shifting of immense quantities of the loose sand of maritime and inland deserts, gradually covering large portions of the adjoining cultivated districts, and entombing

whole villages and even towns. Frost by its expansive power separates the particles of rocks, etc., and thus destroys their cohesion, so that when the thaw sets in these particles easily crumble away. Drought or desiccation, by abstracting moisture from the softer and more exposed substances, also destroys the cohesion of their component particles, and thus performs in summer a part closely analogous to that of frost in winter, both facilitating the crumbling of the surface materials, which are thus more easily brought within the reach of aqueous action. The action of avalanches and glaciers is also very important, the former carrying with them a vast quantity of debris, the latter transporting even blocks and fragments of rocks of great weight to considerable distances. The air also acts chemically on all exposed surfaces, 'weathering' the hardest rocks as well as the softer materials, its oxygen acting specially on ferruginous rocks, while its carbonic acid disintegrates all those rocks which contain lime. Purely aqueous agencies, such as rain, rivers, springs, sea waves, are also productive of great changes: rain softening and percolating through the surface soil; rivers cutting channels out of the solid strata; springs dissolving the minerals through which they pass; sea waves gradually washing away the cliffs skirting the shore—the materials thus removed being deposited at the bottom of the sea or lakes. It is true that, in a comparatively even climate like ours, the effects of atmospheric and aqueous agencies may at first sight appear insignificant and scarcely worth notice; but none the less surely do they change the aspect of a country, although their action is so very gradual as to be almost unperceived by the most careful observer. The wasting influences of these two forces are more or less counteracted by the successive accumulations of organic remains. By the growth of vegetation, lakes once of considerable depth have been made unnavigable or even completely filled up. We have already adverted to the chemical action of the atmosphere. Besides this, rocks act chemically on each other, both below and at the surface. The formation of coral reefs is partly a chemical process. The chemical action of the alkaline earths upon water has been by some supposed to be the cause of present interior heat. So that the external forces acting upon the earth's crust superficially may be classed as (1) *Atmospheric*, (2) *Aqueous*, (3) *Organic*, (4) *Chemical*. As regards the *internal forces*, which, acting below the surface, often cause vast changes, either temporarily or permanently, we have in the two preceding chapters dwelt at some length on the two phases of volcanic energy, as exemplified in earthquakes and volcanic eruptions, which, notwithstanding their violence and apparently extensive power, yet produce at most local changes only, and these bear no proportion to the extensive secular or slow changes of the earth's crust. The successive accumulations of erupted matters, the sudden upheaval or depression of portions of the earth's surface, the fissuring of the crust, may be all traced to volcanic activity. But besides these spasmodic movements, there are slow movements of upheaval and depression constantly going on. From various reasons, which we shall specify more particularly when we come to treat of the causes of these secular movements of the earth's crust, it seems improbable that they are primarily due to the same force as earthquakes and volcanic phenomena, at least of the same kind. This will be seen when we consider that areas of elevation or depression are not, generally speaking, coincident with the lines and centres of volcanic action; in fact, slow upheavals and subsidences of the earth's crust cannot possibly be due to the same cause as sudden upheavals and depressions consequent on volcanic eruptions and earthquakes, and must therefore be otherwise explained.

69. **Secular Movements of the Earth's Crust.**—Besides the sudden movements of upheaval or depression which result from volcanic or seismic energy, it has been definitely proved that the earth's crust is subject to secular or slow changes as well—that is, that whereas the upheavals and subsidences due to internal igneous forces are sudden, other movements of upheaval and depression on a far more extended scale are taking place, so slow as to be almost unperceived, and it is only by comparing the records of ages that their full importance can be realized. It is to these slow changes that the term 'secular' is given. And from the accumulated evidence gathered from all parts of the globe, it would appear that the whole surface is more or less affected, either rising or sinking, and that these effects are more perceptible in some parts than others; and that if we could obtain daily intelligence from all parts of the earth, we would be astonished at the extent of surface over which these movements may be perceived. The magnitude and importance of these secular movements are perhaps hardly considered fully, from the difficulty of perceiving such slow changes—changes of only a few feet in a century. We are, indeed, apt to exaggerate the effects of volcanic energy, which, being sudden and perceptible, seem at first sight an exhibition of a power of much

greater importance, in altering or modifying the external aspect of the globe, than those slow protracted changes to which we have referred, and which take ages for their accomplishment. Proofs of secular movements have been found in all parts of the earth, from the frozen poles to the scorched equatorial districts, and, although in some places apparently coincident with the present lines of volcanic action, are also met with in other parts in which no volcanic activity has been manifested, at least within the historic period. Such facts lead us to the inevitable conclusion that the secular movements of the earth's crust are due to a far more widely-diffused and permanent force than that to which volcanic action is due. The importance of these movements in modifying the conditions of organic existence is very considerable. Temperature and rainfall change, and consequently the animal and vegetable life of the district are slowly, indeed, but none the less surely, affected, and, it may be, in lapse of ages entirely altered. There are, as we have just said, ample proofs of these movements. Raised sea beaches and marine terraces testify in the clearest manner of former gradual upheaval; submerged forests and coral reefs prove conclusively the reality of subsidence. Let us now consider these movements separately, noticing the most remarkable instances in each case, and in conclusion give very briefly our opinion as to the probable cause or causes of these movements of upheaval and depression, how far coincident with, or whether entirely different to, those which produce volcanic phenomena and earthquakes.

70. **Movements of Upheaval.**—Sedimentary or stratified rocks, as we have said, have been formed

by the deposition of sediment at the bottom of the sea or lakes in layers or strata. It follows, then, that by far the largest portion of what is now dry land must have been at one time under water, and, as the sequence of the strata clearly proves, must have been again and again depressed under and elevated above the water.

The fact that remains of corals, shells, and other marine products are often found at great elevations, proves that the sea bottom must have been upheaved at least to that extent; and it is very probable that the process was slow, exactly like the present secular movements. We have said that raised beaches and marine terraces are evidences of upheaval; that they are indeed indisputable proofs will be seen, if we consider them closely. Such beaches or terraces are generally only slightly elevated above sea level, and usually bounded on the landward side by a steep cliff, or a highly-inclined slope. This cliff is often pierced by hollows and caves, the sides of which, as well as the whole base of the cliff, have evidently been subjected to wave action. Are we, then, to conclude that the terrace or raised beach now intervening between the cliff and the sea has been formed by the accumulation of materials thrown up on the shore by the waves? If so, such terraces would show signs of increase. Is this the case? No; for if the outer edge of the terrace be closely examined, it will be seen that portions of it are continually being undermined and washed away, and that in time, supposing the terrace to be immoveable, the sea would cut its way through it, and dash its waves against the base of the cliffs, as before. How, then, can we explain the existence of these raised beaches? Supposing, for instance, a certain terrace to be 12 feet above the sea level, are we to think that the sea has subsided to the extent of 12 feet at that point? If so, it must necessarily have subsided to the same extent all over the world, and therefore terraces 12 feet above the sea level would be found in all parts of the earth. Do we find this to be the case? No. Such terraces are only met with in certain localities, and, further, are not of the same elevation, varying in height from two or three to hundreds of feet; so that we are driven to the conclusion that the cause is the elevation of the beach itself, and not the subsidence of the sea. And it is to beaches thus elevated that the name *raised beaches* has been given. In some places there are several terraces, one above the other, which show clearly that the elevating force was intermittent in its action, and that each terrace marks a period of comparative quiescence between two successive upheavals. And it may be said that, generally speaking, secular movements of the earth's crust are intermittent in their action, periods of comparative activity being followed by periods of comparative quiescence. As we said before, such movements are now going on perceptibly in many parts of the world, and are slowly but surely changing the physical character of those parts. The rate of 'secular' upheaval may be said to be generally about 2 or 3 feet in a century. Thus we see that no part of the earth's surface can be said to be absolutely at rest at present, and we have ample evidence to show that such was not the case in the past; and there is every reason to believe that, unless some unprecedented obstacle presents itself, these secular movements of the earth's crust, by the gradual elevation of the present sea bottom, accompanied by as gradual a subsidence of the existing dry land, will ultimately result in a total change in the present physical aspect of the earth's surface.

71. **Movements of Depression or Subsidence.**—We have said that raised beaches and marine terraces are conclusive evidences of a gradual elevation or upheaval of those districts in which they occur; but we have also quite as conclusive proofs of exactly opposite movements—that is, that while some parts of the earth's crust are being slowly elevated, other parts are being as gradually depressed. *Submerged forests* and *coral reefs* are among the most direct proofs of recent subsidence. Submerged forest-beds occur all along the British coasts, and are generally about 2 to 6 feet thick. Trunks, roots, nuts, and seeds of the trees are found embedded in the partly-formed lignite or peat. Now it is evident that the trees, chiefly oaks, firs, hazels, birches, and alders, of which the stumps, etc. are thus preserved, could not possibly have grown in that position, but must have flourished for long years (as is proved by the great thickness of many of the submerged trunks) above sea level. The question, then, is this, whether the forest was submerged by the subsidence of the land, or whether the sea rose and covered it. As regards the latter, we have already shown that any permanent elevation of the sea in one place would necessarily imply a corresponding rise all over the world; and as we have no data whatever to conclude that this ever was the case, we must accept the first explanation, viz. that the forests, of which the trunks, etc. remain under water, were submerged by the subsidence or sinking of the land below the level of the sea, and the consequent inrush of the water. Another conclusive and, indeed, indisputable

proof is furnished by the coral reefs of the Pacific. Coral zoophytes, as we have said, cannot live at greater depths than from 20 to 30 fathoms. Masses of coral, however, are found at much greater depths, and although the enclosed lagoon is often shallow, the reefs on the outer side rise from depths of 3000 or 4000 feet. Again we are faced with the double explanation of a rise of the sea or a subsidence of the land; and as the reef-building corals cannot live at much greater depths than 100 feet, the sea must have risen very considerably in those parts, or the land upon which the corals first founded their structure must have subsided. The absurdity of the former is manifest, for it implies a corresponding rise all over the world. We must therefore account for the great height of these reefs by supposing that, although the corals began to build in shallow water (not more than 100 feet deep), the reef, once begun, would grow higher and higher until at last close to the surface. Then the land on which the reef rested gradually subsided, but so slowly that the zoophytes, continually building upwards to the surface, still kept their structure at or close to the surface. Here, then, we have most conclusive evidence of the secular subsidence of a vast area. At first the foundation was laid in shallow water, and, being built up to the surface, enclosed partly or entirely an island of considerable elevation. As the island gradually subsided, the reef as gradually grew upwards to the surface. At length, the highest point of the island having disappeared, the reef alone would be seen at the surface as an atoll. It is noticeable that all, or nearly all, the islands thus surrounded by coral reefs are of a volcanic character, and may well be supposed to be the elevated peaks of a once vast continent, of which, if the present movements still continue, every vestige will ultimately disappear; except, perhaps, the coral reefs, which, overgrown and covered with tropical verdure, will seem to be, as it were, unfading wreaths on the watery grave of a sunken continent.

72. **Causes of Slow Upheaval and Subsidence.**—As we remarked before, there are many theories advanced to explain the secular movements of the earth's crust. Some geologists place these movements in the same category as volcanic phenomena and earthquakes, as being due to the same cause. But the areas that can be proved are now affected by secular movements are far more extensive than those in which volcanic or seismic activity is manifested, and vast tracts of land, although showing unmistakeable signs of slow upheaval or subsidence, are at present entirely non-volcanic in character; so that evidently it cannot be the same force, at least of the same kind, that produces such diverse effects. Volcanic or seismic activity is at the most local and sudden; secular movements affect vast areas, and, as geological records show, have at various times resulted in the immersion of what is now dry land repeatedly under water, and consequently as often in the upheaval into dry land of the present ocean floor. To some other general and far more permanent cause, then, must be referred the secular movements of the earth's crust. Accordingly, some scientists refer these movements to the unequal expansion caused by heat; for it is well known that different rocks expand unequally when heated, and that therefore the preponderance in any district of rocks, such as sandstones, etc. (which expand fully twice as much as granite), if their temperature were raised, would show a perceptible amount of expansion—or, in other words,

that district would be slowly elevated, while other districts in which the less expansible rocks preponderate would not show such an elevation; and thus it is explained how secular movements affect certain areas only. Lyell calculates that, if a mass of sandstone one mile in thickness were heated to 93·3° C., the rock would be lifted 10 feet; or if a mass 50 miles thick were heated to about 4000° C., an elevation of about 1500 feet would be the result. On the resumption of the original temperature, a corresponding amount of depression would of course ensue; so that, if from any cause an increase in the temperature of the solid crust takes place in any district, a more or less degree of elevation takes place; while, if the normal temperature in any part falls, a more or less degree of contraction or subsidence follows. Another eminent scientist refers the phenomena of upheaval more especially to the chemical action of carbonic acid on silica, which is an important constituent in some of the older rocks. The specific gravity of the mineral resulting from this action is less than that of the original rocks, but its volume or bulk is much greater; the increase in granite, when so acted upon, amounting to at least 30 per cent., while in basalt the increase is not much short of 100 per cent. And so he avers that the percolation of these rocks with carbonic acid accounts primarily and directly for the slow upheaval or elevation of the surface consequent on the expansion of the underlying mass, and indirectly, also, by the lateral pressure caused by any considerable expansion in certain parts, for the slow depression or subsidence of other parts. Another theory has been advanced to explain these movements, which discards subterranean agency altogether as a factor in producing these secular changes of level, and instead endeavours to show that in the past, at least, they are the result of a displacement of the earth's centre of gravity by a preponderance of ice in the northern hemisphere during the glacial epoch. This theory undoubtedly may be made to explain very considerable changes in the level of the land; but it is doubtful if the secular movements now taking place, as well as those of the geological epochs, may be satisfactorily referred to this single cause. Most probably these secular movements of the earth's crust are due to the gradual cooling of the earth as a whole. To understand this more clearly, let us revert for a moment to nebulæ, which were formerly supposed to be star clusters. Subsequent observations (more especially spectroscopic), however, dispelled this belief, and showed that the nebulæ are really masses of incandescent gas. From these and similar observations, many astronomers have been led to conclude that the stellar (as well as the solar) systems have been formed by the detachment of masses of still incandescent gas from the parent mass, these various masses forming the planets, and the parent mass the sun or centre of the system. The earth, then, is supposed to have been originally a mass of incandescent gas detached from the sun, and in this state it both gave off and received heat. If the heat radiated into space had been equal to that which the mass received from the other masses, then the earth would have retained its normal gaseous state. But we know, from direct observation, that at least the outer part of the earth is solid. The earth, then, must have cooled—that is, the heat radiated into space must have exceeded very considerably that received from other heated masses; and so the mass gradually cooled and ultimately assumed the liquid state. The next step in the process was probably the solidification of the external film; but, as Sir William Thomson has clearly shown, this hardened film, on being broken up into fragments, having a greater specific gravity than the enclosed liquid, would sink into the mass, and being drawn with equal force to the centre, would cluster round that point, forming a solid core or kernel. Fragments of the external solidified films continually fell, and so the core grew larger and larger, until at last the whole mass was more or less solidified. But, as we have seen when treating of volcanic phenomena and earthquakes, the interior of the earth is still in a condition of great heat, and there are undoubtedly immense subterranean cavities filled with matters still liquid or molten, so that we cannot regard the earth as entirely solid or cooled. The earth, then, still radiates heat into space. Now this radiation of heat—or, in other words, the lowering of the temperature of the mass as a whole—is followed by a contraction or diminution in bulk. The exterior, having once become cold, will radiate its heat comparatively less rapidly than the still highly-heated core—or, in other words, the core loses heat faster, comparatively speaking, than the surface does. The result is, that the core contracts or shrinks in from the surface crust, which, from its curvature and comparative rigidity, can only follow this shrinking by alternate downward and upward bendings; thus giving rise to what are known as the secular movements of the earth's crust, the downward bendings in one place constituting depression or subsidence, the upward bendings upheaval or elevation. Thus we may account for these movements in a scientific yet perfectly natural manner. There only remains to note how this theory harmonizes with their secular character; and in this respect it accords perfectly with observed facts, for the radiation of the interior heat is so slow that it scarcely, if at all, affects the surface temperature. But an infinitesimal internal contraction consequent on radiation affects the surface crust perceptibly, and, as the degree of slow upheaval or depression amounts to only a few feet in a century, it is evident that the shrinking or contraction of the internal core must be correspondingly slow—so slow, indeed, that, as we have said, the interior heat lost or radiated cannot be said to influence the surface temperature of the earth.

73. **Areas of Elevation and Subsidence.**—In conclusion, let us point out very briefly the principal localities in which evidences confirmatory of secular change of level of the land are found. Commencing with the British Isles, we find unmistakeable signs of elevation, sometimes alternating with equally conclusive proofs of depression, along the whole of the southern and eastern shores of England and the eastern coast of Scotland, the amount of elevation in the former varying from 1 or 2 to 50 or 60 feet, in Scotland generally about 20 feet. Crossing to the Continent, the most remarkable instance of elevation is that of Northern Scandinavia, between the Baltic and the Atlantic. The degree of elevation is clearly shown by the height to which ancient sea-beaches have been raised; and as there are several lines of these raised beaches or terraces, it is clear that the elevating force was not equally active at all times (in which case the coast would not present its present terraciform appearance), but was at some periods comparatively

quiescent, during which the several beaches were formed. It is also probable that until comparatively recent times the Baltic and White Seas were connected together by a channel or strait, the obliteration of which plainly shows that the level of the intervening district must have changed—that is, that it must have been upheaved; for if no change of level had taken place, the two seas would still be connected by the strait as formerly: the evidence, then, of upheaval, in this case at least, is incontrovertible. All that part of Greenland north of lat. 75° also presents evidences of upheaval, marine remains being found sometimes nearly 40 feet above the level of the highest tides. The cluster of islands to the north and north-east of North America also show signs of upheaval in the position of driftwood, etc., which are found even as high as 30 feet above the highest tide-mark; indeed, it seems probable that all North America within the Arctic Circle, and even as far down the western coast as British Columbia, is slowly but steadily rising. The terraces around the great North American fresh-water lakes also indicate that the upward movement is not confined to the seaboard, but also affects the entire intervening country. In Nova Zembla and Spitzbergen, marine drift, bones of whales, etc. are found at an elevation considerably higher than the present sea level; and, of course, as it is certain that the sea cannot possibly have sunk to that extent, it must be that the land, which when it received its load of drift, etc. was at sea level, must have been elevated at least to that extent. The same elevating force has been, and most probably is at present, at work along the whole of the northern coast of Asia, extending south even as far as the

Gulf of Peecheelee, the amount of elevation in some places being nearly 200 feet. The Siberian Tundras are in fact but a comparatively recently raised sea-bed, being covered with the same kind of shells, etc. as are found in the adjoining sea. So we see that the whole of the northern coast of Europe and Asia, from Norway to the Gulf of Peecheelee, and inland as far as the central Asiatic highlands, have been upheaved, most probably during a comparatively recent period, and that the elevating force in many cases seems to be still in action. Passing over to North America, evidences of upheaval are found in Newfoundland, Labrador, and the Arctic Archipelago to the north. In South America the most remarkable instances are found in Patagonia, along its eastern coasts from Tierra del Fuego to the La Plata, and on the western coast in Chile, Bolivia, and even Callao in Peru. In the African continent, which, as we have said, is remarkably free from volcanoes, secular movements affect wide areas;—the greater part of the eastern coast, from Cape Colony to Zanzibar, is evidently rising. The great Desert of Sahara, again, like the Siberian Tundras, is but a recently-elevated sea-bed; and as shells, etc. are found in some places as high as 800 feet, the land must have been upheaved to at least that extent. Raised coral reefs also indicate upheaval in the New Hebrides, New Guinea, etc., as also a great part of the southern coast of Australia, and portions of Tasmania and New Zealand.

In the northern hemisphere, perhaps the most remarkable proofs of subsidence are found in South Greenland, southern part of Sweden, the English coast between the Humber and Tees, the whole of the north-western coast of France, and especially

Holland, which, but for the immense dykes thrown up, would nearly all be covered with water. The eastern coast of the United States is also gradually subsiding. In the southern hemisphere similar evidences are found in Brazil, Guiana, South-east China; but the most remarkable is the coralline zone of the South Pacific, which area was at one time evidently occupied by a vast continent having a length of over 4000 miles, the peaks of its submerged mountains being still visible as islands encircled partly or entirely by coral reefs. We have elsewhere shown that coral reefs are indisputable proofs of the gradual subsidence of the districts in which they are found.

CHAPTER XI.

ON THE SEA.

74. **Composition of Sea Water.**—Sea water differs from that of rivers and lakes in being more or less salt. The *saltness* of sea water is due to the presence of certain solid matters held in solution in it. These saline matters are not chemically combined with the water (*i.e.* sea water is not a chemical compound), but the various ingredients are simply dissolved or mixed, or in other words are held in *chemical solution* in the water, and may therefore be separated from it by allowing the water to evaporate. The solid matters held in solution amount to about 3·5 per cent.—that is, every 100 pounds of sea water contains 3½ pounds of solid matters, or nearly half an ounce to the pound. They consist chiefly of common salt (three-fourths of the whole), magnesium chloride (one-tenth), sulphate of magnesia (a little more than one-twentieth), sulphate of lime (one-twentieth). Other ingredients, such as silica, carbonate of lime, potassium chloride, sodium, bromide, etc., are also found in small quantities; in fact, sea water contains minute quantities of nearly all, if not all, the known elementary substances. It has been computed that the total quantity of saline matters dissolved in sea water would, if spread out equally, cover an area of seven

million square miles, or twice the superficial extent of Europe, to a depth of one mile. This, of course, is but a rough approximation, and, considering the fact that every cubic foot of sea water yields two pounds of salt, and that the ocean has an average depth of 3 or 4 miles, is most probably much below the actual quantity. The proportion of solid matters held in solution is very nearly the same everywhere in the open ocean, this uniformity of composition being evidently due to the unceasing movements and consequent commingling of its waters by waves, tides, and currents. But in gulfs, landlocked seas, etc., there is a comparatively slight difference in the saltness as compared with the ocean; this difference is entirely due to local causes (often merely temporary), such as the degree of evaporation, the proportion of rivers received, etc. As we have said, the saltness of sea water is not quite uniform in all parts even of the open ocean, although very nearly so. The areas of maximum saltness occur along the parallels of 17° south and 22° north latitude—that is, in the Trade Wind regions; and from these towards each pole the saltness gradually diminishes, but only to a slight extent; for instance, the difference in the quantity of solid matters in sea water at 14° north latitude, and in that at 80° north latitude, was found to be only 0·46 per cent. The greater degree of saltness in the regions of the Trade Winds is due to excessive evaporation, while the slight diminution in saltness in the Polar Seas in certain seasons is due to the melting of icebergs. Inland seas receiving many rivers, and subject to but little evaporation, are generally fresher than the ocean,—the Baltic, for instance, being only half as salt, and at some seasons nearly fresh and drinkable. But if an inland sea, although receiving considerable quantities of fresh river water, is yet subject to active evaporation, its waters will be nearly if not quite as salt as those of the ocean. For instance, the Caspian receives by the Volga alone as much water as the Mediterranean receives from all the European rivers flowing into it, and has no outlet. Notwithstanding this, the waters of the Caspian are nearly as salt as those of the Atlantic. Again, the Mediterranean, although receiving a vast quantity of fresh water, is very nearly twice as salt as the English Channel. Again, if an inland sea, or nearly landlocked arm of the sea, be subject to active evaporation, and yet receive no rivers, at least none of any considerable size, the water will have an excess of saltness, *e.g.* the Red Sea. The specific gravity of sea water, as compared with pure fresh water, is found to be much greater (the mean being as 1·0275 is to 1); and as the specific gravity of sea water depends principally upon its saltness (although influenced by its temperature as well), therefore the salter the water is the greater will be its specific gravity. (This, however, we shall explain more fully farther on.) Sea water, then, bulk for bulk, being heavier than fresh water, the latter will float on the surface of the former, and will not readily mingle with it. The surface water of the sea, therefore, is not so salt as that at great depths. Thus water brought up from a depth of 4000 feet in the Gulf of Guinea, 100 miles from the coast, yielded 4·5 per cent. of saline matters, or was 1 per cent. salter than that at the surface. But this, it must be observed, is not without exception. Captain Ross found that the specific gravity, and therefore the saltness of water, taken at a depth of 4000 feet, differed but very slightly from that at the surface. But in the vicinity of large estuaries, or immediately after heavy rain, the surface water is, as we have said, fresher; in fact, water fit for use has been skimmed from the surface of the sea several miles out. The fresh water of the Amazon may be perceived for more than 200 miles out in the Atlantic. The salinity of sea water makes a wide difference as regards properties between it and fresh water. In the first place, it is much less vaporizable—that is, a smaller amount of moisture will be evaporated from a given area of sea water than from an equal area of fresh water under similar conditions. In the next place, it does not freeze so readily,—fresh water freezes at 32° F., sea water not until the temperature sinks to 28½ F., —with what result, especially as regards commercial intercourse between maritime nations, is evident. Absolutely pure water, too, could not possibly sustain the myriads of animals found in the sea, especially the vast numbers of minute microscopic animals, the protozoa, which derive from it the carbonate of lime and silica of which their shells are composed; nor would the reef-building zoophytes find in fresh water the necessary amount of lime which they secrete. As to the source or cause of the universal salinity of sea water, many explanations have been given. According to some, the water of the ocean, being originally fresh, acquired its present saltness by dissolving the saline rocks in its bed, the saline matters thus dissolved being spread through the water by means of waves, tides, and currents. Others suppose that the salt and other matters were gradually carried into the sea by rivers, which dissolved them from the soil through which they passed. According to the latter view, the saltness of the sea must be continually increasing, as the matters carried down by rivers are not removed by evaporation, but are left behind to accumulate indefinitely. But there are many objections to this view, for we have no data to conclude that sea water is salter than it was in the earliest ages; in fact, geological observations on former marine organisms tend to prove that the sea was most probably similar in composition at the earliest epochs as at present; so that, as regards saltness, the ocean must be regarded as having long since arrived at a state of equilibrium, the amount of saline matters brought down by rivers, or dissolved from the shores, or otherwise obtained, being nearly equalized by the amount appropriated by the myriads of shell-fish, corals, sponges, etc. with which it teems, while the amount still in excess is most probably used in the formation of new calcareous and saline rocks at the bottom of the sea. So that here, as in almost every department of nature, there is an endless cycle of waste and supply in ceaseless operation.

75. **Colour.**—The colour of sea water varies according to the depth, degree of salinity, and other causes, being in the open sea a rich blue, and in shallow waters more or less green. Blue is most probably the natural colour of pure water, the greenish tint of shallow water being probably due to the reflection of the yellow colour of the sandy bottom mingling with the natural blue of the water. The depth or richness of colour seems to be due to the degree of saltness. Thus the waters of the comparatively fresher Polar Seas are of a light green, while those of the Trade Wind region are dark blue. The Mediterranean in a storm appears of an inky blue, but generally it is of a deep azure blue. Other parts of the sea are coloured by the vast numbers of animal and

vegetable organisms they contain,—*e.g.*, the Red Sea, Vermilion Sea (Gulf of California), the Green Sea (or Sargasso Sea, west of the Canaries and the Azores). The Yellow Sea, off China, derives its peculiar colour from the mud brought down by the large rivers entering it. The presence of large quantities of fresh water (from rivers, melting icebergs, etc.) diminishes or tones down the normal deep-blue colour of the open sea. Other parts of the sea are of peculiar colours,—*e.g.*, the Black Sea, dark purple; Gulf of Guinea, white; Persian Gulf, green, etc.

76. **Depth.**—With the exception of the results arrived at by the *Challenger* Expedition, not many really reliable soundings have been taken, at least in the open ocean; in fact, 'sounding' has only recently been so perfected as to furnish accurate and reliable results. The numbers, then, given by navigators, even in comparatively recent times, are open to doubt; and more accurate soundings, subsequently made, prove conclusively that the reports of depths of 40,000 and 50,000 feet were incorrect. We shall therefore ignore these earlier results, and give very briefly the general results of the more recent soundings as more reliable and accurate. Captain Maury, in his admirable work, the *Physical Geography of the Sea*, first drew the attention of geographers to this interesting subject, which is of great practical value as regards submarine telegraphy, etc. He pointed out that a great ridge or plateau extends from Ireland to Newfoundland, a distance of 1640 miles, at a maximum depth of 12,000 feet. The greatest ascertained depth in the Atlantic is 23,400 feet, or nearly 4½ miles; in the Pacific, 26,850 feet, or nearly 5 miles; in the Mediterranean

(western basin), 13,000 feet; in the Mexican Gulf, 8000 feet; in the Red Sea, 6300 feet; in the Baltic, 840. The mean depth of the ocean has been calculated to be at least 21,000 feet, or about 4 miles. But this is doubtful, as we know from direct measurements that a very large proportion of the sea is not more than 2000 or 3000 feet deep; therefore, in order to make up a mean of 4 miles, extensive portions of the sea must have a depth of 8 or 9 miles, which recent soundings have proved to be erroneous. The greatest absolute depths are found in the Indian and Southern Oceans; the Atlantic is on the whole deeper than the Pacific; the Antarctic becomes shallower towards the poles; while the Arctic Ocean, although in some places very deep, is on the whole the shallowest of the great oceans. Some of the principal results of the *Challenger* Expedition are as follow:—The greatest ascertained depth in the Atlantic was between the island of St. Thomas and the Bermudas: this measured 3875 fathoms, or 23,250 feet; the greatest depth in the Pacific, some distance south of Japan, 4475 fathoms, or 26,850 feet. The depth as well as the temperature, etc. of the water was ascertained at 150 stations in the Atlantic, and 100 in the Pacific. From the data obtained, the average depth of these oceans was estimated to be about 2000 or 2500 fathoms, or about 13,000 feet, that of the eastern trough of the great Atlantic basin being computed at 2000 or 3000 fathoms, or 15,000 feet. In the Indian Ocean (Arabian Sea) the greatest depth ascertained was 2200 fathoms.

77. **Pressure.**—The pressure of the water at great depths is such that, until recently, it was believed that no animal or vegetable life could

exist under it. Vast numbers of various kinds of marine organisms, sponges, starfishes, foraminifera, etc., however, are now known to live at depths of from 5000 to 13,000 feet. The enormous pressure at such great depths may be inferred from the following considerations. Ignoring the fact that water is slightly compressible, about $\frac{1}{340}$ of its own bulk at a depth of 1000 feet, and therefore is heavier or denser as the depth increases, let us take 62 pounds as the weight of a cubic foot of water. At a depth of 1000 feet the pressure on a square foot will be 1000 × 62 pounds, or 62,000 pounds, or nearly 28 tons, or nearly $2\frac{1}{2}$ tons on a square inch. At a depth of 10,000 feet the pressure will be 280 tons on a square foot, or nearly $23\frac{1}{2}$ tons on a square inch; while at 13,000 feet it will be 364 tons on a square foot, or over 30 tons on a square inch. How the animals, in many cases of the most delicate organization, brought up from such great depths, could possibly live under such enormous pressure is indeed surprising; but on consideration the fact is not so incredible as it seems at first sight, for it may be satisfactorily explained by a comparison with the conditions of animal life on the land under atmospheric pressure. The atmosphere, for instance, presses upon the body of a man with a weight of nearly 15 tons. Now a fraction of this weight, if applied in any other way, would crush a man to death. How, then, is this great pressure supported, and indeed is not even felt? The reason is that, first, the pressure is equal on every side, and that the pressure of the air outside is equalized or supported by a portion of the same element inside; the man therefore feels no weight, being in a state of equilibrium as regards the pressure. Or, taking another illustration, say a thin bladder filled with air. Now this bladder is pressed on the outside by a weight of several hundred pounds, and yet is not injured in the least, the pressure on the outside being supported by the air inside, which is under the very same degree of pressure. Again, a soap bubble preserves its form for a short time under the full pressure of the air. Or suppose a very thin sheet of paper, say a foot square, be immersed horizontally in water, at a depth say of a foot. Now a cubic foot of water weighs 62 pounds. The pressure, then, on the sheet is 62 pounds, and yet we see it is not torn, but still keeps its cohesion. The reason is that the water below the sheet supports that above, or, in other words, the pressure above and below is equal. But if there were no water below, the sheet would be rent instantly under the weight of a much smaller amount of water above it. Applying these principles to the animal life of the deep sea, we see that the enormous pressure of the superincumbent mass is supported by a portion of the same element (and therefore under the same pressure) *inside* the animal, as well as by the equality of the pressure on all parts, so that the animal is in equilibrium. Reverting to atmospheric pressure, we know that it is an absolutely necessary condition of the existence of animal life on the earth's surface, and that any considerable variation in this respect is always attended with injurious results, as the experience of pearl divers and aeronauts proves,—that is, that any considerable increase or decrease of the normal atmospheric pressure is injurious, if not fatal. Now many of the specimens of deep-sea life obtained by the naturalists of the *Challenger* Expedition were either dead or dying when brought to the surface. It was suggested that the animals were killed by the fresher surface water. But when we consider the slight difference in the proportion of saline ingredients between the surface water and that at great depths (generally amounting to only 1 per cent.), their inability to exist at or near the surface cannot reasonably be attributed to this cause alone, although probably partly so. The reason, in our opinion, was the difference in pressure, which, as we have seen, is always attended with injury to animal life. For instance, a man, if removed from the earth's surface to the higher regions of the air, would undoubtedly be killed by the expansion of the air within him; and the death of the specimens obtained was most probably due to the same cause; the enormous pressure of the water in the latter case, and of the air in the former, being a *sine qua non* of their existence.

78. **Form of Sea-Bottom.**—The knowledge we possess of the 'form of the sea-bottom,' especially as regards the open sea (with the exception of the Atlantic), is, even at the present time, scant and imperfect. One cause of this is that the determination of great depths has but recently been made trustworthy by means of improved apparatus, etc., so that it was indeed almost useless to incur great expenses to obtain results which, after all, were scarcely credited. Witness the reports formerly published of depths of 40,000 and 50,000 feet, which have since been shown to be erroneous. But now that the art of 'sounding' has been so perfected that the greatest reliance may be placed on the results obtained, scientific explorers have the encouragement that their labours will not only be duly appreciated, but also that the results of their observations as to depth, etc. will be credited. Another

cause may doubtless be found in the fact that, to meet the essential requirements of navigation, it was only necessary to 'sound' near the shore, at entrances to harbours, etc., and that the execution of a series of deep-sea soundings entailed heavy expenditure. Accordingly, until the recent explorations in connection with submarine telegraphy, and by the *Challenger* and other national scientific expeditions, the prevalent notion was that, as regards its superficial conformation, the sea-bed was indeed but the counterpart, as it were, of the land, having its mountains and valleys, table-lands and plains, steep ridges and deep gorges—in fact, it was argued that, it being evident from geological observations that the present sea-bed, being but the submerged surface of what was once dry land, must necessarily present in detail those physical features characteristic of the land. Is this the case? Generally speaking, it is not. Recent explorations in the Atlantic and elsewhere all tend to the conclusion that the sea-bed, as a rule, presents but few of the characteristic inequalities of the land, there being no such abrupt descents or deep chasms as generally supposed, but, on the contrary, that it may be described in general terms as gently undulating. It is true that there are vast differences between various parts as regards depth, often amounting to thousands of feet, but the descent, at least in the 'lines of soundings' hitherto taken, is by a gentle gradient. Of course there are many exceptions to this rule, as to almost all general rules. We mean those parts of the sea-bed subject to volcanic disturbances, or where the undulations are broken by vast coral reefs, or immediately round some coasts; notwithstanding which the general statement we have made holds good for by far the greatest portion of the ocean floor. And here we must caution the student as to the sections given of the lines of soundings, which, of course, are only meant to show the depths at the various stations. The proportions of the vertical and horizontal measurements are therefore disregarded, and these two measurements, the vertical and horizontal, not being on the same scale in sections of this kind, the student is apt to form exaggerated and incorrect notions of the form of the sea-bed. That such sections are misleading, if the disproportion of the two measurements be not borne in mind, is shown by the fact that if any section yet made were drawn to a true scale, it would not show any such abrupt descents or ascents as are common on land. We scarcely know how to account satisfactorily for this regularity of the superficial conformation of the sea-bed. The present sea-bed was doubtless at one time dry land, and therefore subject to all the wasting influences of the erosive agencies now operating upon the surface of the land. The absence of the characteristic irregularity of the physical features of the land is supposed to be partly due to marine erosion, as the ground gradually subsided. This process was evidently repeated several times, for there is ample evidence of repeated submergence and upheaval. But after the final submergence, when the sea-bed occupied its present position, it would, as far as we know, be beyond the reach of any of the eroding agencies, being fully protected from atmospheric or aerial action; and as regards being planed down, as it were, by deep-sea currents, we need only remark that their effect would be to produce those features which are conspicuous only by their absence; in fact, it is well known that deep-sea currents do not, and, indeed, cannot, produce any denudation of the ocean floor. In our opinion, the most probable causes of the present regularity were, first, marine erosion during repeated submergences, and, second, depositions of materials worn away from the coasts, or carried down by rivers, or obtained from the myriads of minute organisms with which the deep sea teems; the latter process supplementing the former, the depositions covering and filling any irregularities which still existed. We shall now consider separately the form of the beds of the great oceans, first, however, giving a brief explanation of the *modus operandi* of deep-sea sounding.

79. **How Deep-sea Soundings are taken.**—The art of sounding, as we have said, has only recently been so perfected as to justify us to accept the result obtained as perfectly trustworthy. Of course the practical determination of the depth at any station is made by simply letting down a line with a heavy weight attached to it from a ship, or, better, a boat in still water. This has always been done; but the inaccuracy of the results formerly obtained were due, in the first place, to the uncertainty as to whether the weight had touched the bottom or not; and, secondly, supposing that the weight had touched the bottom, it was doubtful whether the length of line out did not exceed the vertical depth; and, lastly, supposing that the weight had touched the bottom, and that the line was tense throughout, it was questionable whether the boat or ship had not shifted its position during the operation. These obstacles to accurate sounding have been thus obviated. And first as regards the uncertainty whether the weight had touched the bottom or not. It was formerly supposed that,

when the weight touched the bottom, the line would cease to run out. But the reports of depths of 40,000 and 50,000 feet roused suspicion that this supposition was not in accordance with the real fact. By means of repeated observations, and experiments as to the rate at which the line ran out, the law of descent was ultimately established. This law may be thus briefly stated. In the first place, it was found that the line does not run out at a uniform rate, but at a certain decreasing rate, owing to the greater density of the water; and, secondly, that this irregularity in the rate of running ceases when the weight touches the bottom, and if the line be then deflected by under-currents, it is carried away at a uniform rate. It is, therefore, not difficult to determine whether the weight has touched the bottom or not, by observing the rate at which the line runs out. This would decrease gradually until the weight touched the bottom. The line then, if acted upon by under-currents, would begin to run out at a uniform rate; so that, by noticing when the rate changed, it would be known when the weight touched the bottom. But, independently of these observations, experienced observers are generally able to tell when the weight touches the bottom. It being found from experience impossible to raise the weight after being let down, it was therefore necessary to cut the line. This, however, has been obviated by the use of Lieutenant Brooke's Deep-sea Sounding Apparatus, in which the weight on touching the bottom is detached from the line, leaving only a small iron tube to be drawn up again. On the end of this tube some grease or soap has been fixed, so that a portion of the bottom adheres to the tube, and is thus removed and brought up for examination. It used to be commonly said that the weight could never reach the bottom at great depths, but that it would be buoyed up by the denser under water. The absurdity of this notion has been many times practically shown, but on theoretical grounds alone it can be proved to be entirely inconsistent with the known properties of water. For instance, it is computed that in order to double the density of water a depth of no less than 93 miles would be necessary. We all know that no such depth as this is found anywhere, the greatest depth yet sounded being only 4475 fathoms. Now the specific gravity of lead is about 11 times more than that of water. Supposing, then, that there was a depth of 90 or 100 miles, the lead would still be 5 times as heavy as the lowest strata of water, and therefore could not possibly be buoyed up. As regards the second difficulty, viz. the uncertainty as to whether the length of line out (supposing the weight to rest on the bottom) did not exceed the vertical depth, we must revert again to the belief at one time prevalent, viz. that when the weight touched the bottom the line would cease to run out. Reports of such depths as 40,000 and 50,000 feet, however, as before stated, roused suspicion that the line had been deflected from the perpendicular by under-currents after the weight had touched the bottom. The law of descent obviates this difficulty by directing observation to the rate at which the line runs out. The last difficulty to accurate sounding —that is, whether the ship or boat had shifted its position or not—is only felt in the open sea, where there are no fixed objects whose bearings may be taken. This, again, is obviated in a general measure by making the observations in still water, and by sinking the lead from a boat, which in a calm sea is not so liable to shift as a ship is. But these various plans have been almost entirely superseded by Sir William Thomson's patent sounding apparatus, which is founded on the fact that the pressure of the water increases in a certain definite ratio to the depth; and given the pressure, the depth may be easily calculated. The pressure is found in this way: Immediately above the weight, a brass tube, open at the top, but closed at the bottom, is fixed to the line (a fine steel wire, which offers much less, if any, resistance to the water than the 'lines' formerly used). Inside this tube another smaller one of glass is inserted. The latter, however, is closed at the top and open at the bottom. The larger brass tube contains some sulphate of iron, the smaller glass one is coated with a solution of prussiate of potash. The water pressing more and more as the weight sinks, the sulphate of iron is forced into the glass tube, and, acting chemically upon the prussiate of potash, turns it into a deep-blue colour. The height to which the sulphate of iron is forced up in the glass tube depends upon the degree of pressure in a vertical line above it, or, in other words, in the exact perpendicular depth at that point; and therefore the length of line out is of no consequence whatever, as it does not affect the results in the least. The vessel, therefore, need not be at rest during the operation, but perfectly reliable results are obtained even when the ship is going many miles an hour. The line and attached tubes being drawn up, the smaller glass one is laid on a graduated scale, and the degree of pressure, shown by the height of the blue colour, and corresponding number of fathoms are read off and recorded. With the exception of certain enclosed basins, such as the Sulu Sea, the Banda Sea, and the larger eastern and north-western Atlantic basins, the temperature varies considerably. In the Sulu Sea the temperature decreases from 84° at the surface to 50°·5 at 200 fathoms. At all depths below this, even to the bottom at 1780 fathoms, the same temperature (50°·5) is preserved. In the China Sea, with which it communicates, the temperature decreases regularly from 84° at the surface to 37° at the bottom. Of the Atlantic basins, again, the eastern and north-western are protected from the colder polar currents by submarine ridges, which are at depths of about 2000 fathoms. The enclosed water in these basins, then, preserves the temperature of the stratum of water overlying the summits of the ridges, and even to the greatest depths a uniform temperature of 35°·3 in the eastern and 35° in the western has been observed. In the south-western basin the communication with the colder Antartic Ocean is apparently more open, as the bottom temperature in this basin sinks to 31°.

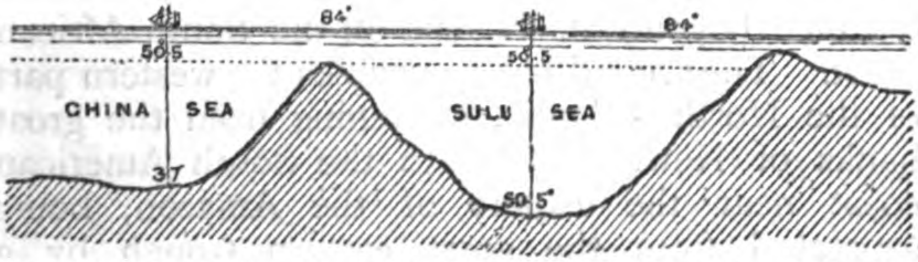


Fig. 13. Showing uniformity of temperature in enclosed basins.

Besides determining the depth, there are other points observed in scientific expeditions, such as that of the *Challenger*, viz. the temperature of the water at different depths, determined by means of the thermometers fixed to the sounding line; the examination of the nature of the sea-bottom, portions of which are brought up by the 'Hydra,' 'Bulldog,' and other apparatus; the determination of the density or specific gravity of the water at various depths; the animal and vegetable life of the various vertical and horizontal zones; and from a series of soundings to examine sections of different parts of the sea-bed, thus giving a general idea of contour of the various basins examined.

80. **Bed of the Atlantic.**—Formerly the Atlantic was described in general terms as a vast canal, the floor of which sloped gradually from the coasts of Europe and Africa on the one side, and from those of the American continent on the other, a line of maximum depth being supposed to be somewhere near the middle. Recent explorations, however, show that the bed of the Atlantic is not one great trough, as supposed, but is divided by considerably elevated submarine ridges into at least four unequal basins. The largest of these occupies by far the greater part of the eastern half of the northern and southern portions of the Atlantic, extending from a submarine plateau, which is the common basis for the British and French coasts, to some distance beyond St. Helena off the South African coast. The second basin occupies the western part of the North Atlantic, stretching from the great banks of Newfoundland to the South American coast near the estuary of the Amazon, being separated from the great eastern trough by a ridge called the 'Dolphin Ridge,' and from the south-western basin by a portion of the 'Connecting Ridge.' The third basin occupies the western portion of the South Atlantic, and is separated from the great eastern basin on the north by the 'Connecting Ridge,' and from the same basin on the east by the 'Challenger Ridge.' The fourth

basin lies south of the main trough, from which it is separated by a lateral ridge running from Tristan d'Acunha to Cape Colony. So that instead of a middle line of greatest depth, there is a long ridge extending from Iceland by way of the Azores in the north, to the island of Tristan d'Acunha, at least not much farther, in the south. This main ridge, of which the northern portion is known as the 'Dolphin Ridge,' and the southern as the 'Challenger Ridge,' divides the bed of the Atlantic into two great canal-like basins, which are further subdivided, the eastern portion by a lateral ridge from the main ridge to Cape Colony, and the western by another lateral ridge, called the 'Connecting Ridge.' The four basins thus marked might be thus designated—the first, the eastern; the second, the north-western; the third, the south-western;

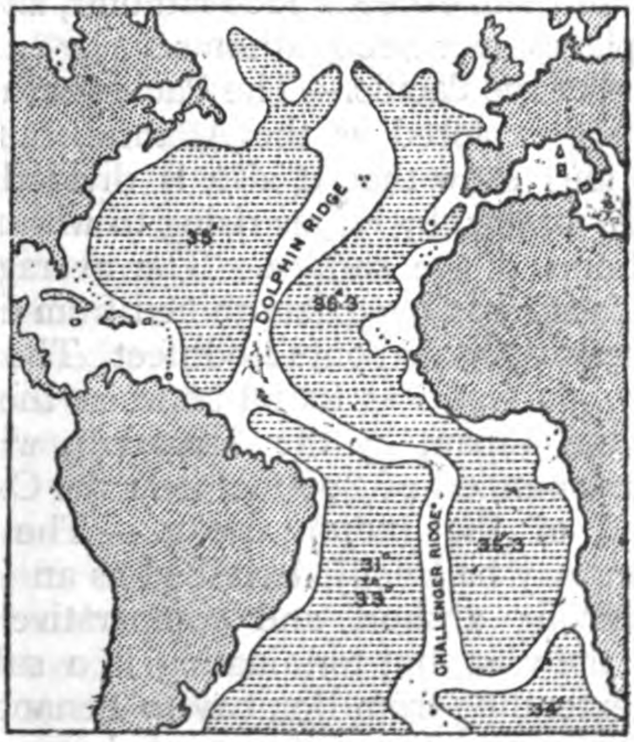


Fig. 14. Bed of the Atlantic.

and the fourth, the south-eastern basin of the Atlantic. As regards the depth, it has been found that each of them exceeds 2000 fathoms, and in the deepest places over 4000 fathoms.

81. **Bed of the Pacific.**—The Pacific has not been so minutely explored as the Atlantic, but recent investigations show that it also is divided into at least three basins, by ridges rising to within about 1800 fathoms of the surface. The average depth of these basins has been determined from tidal and other observations at about 12,000 feet. The greatest depth, 27,900 feet, was found between the Kurile Islands and Japan, by the *Tuscarora*, while the *Challenger* sounded 26,800 feet near the Carolines.

82. **Bed of the Indian Ocean.**—The bed of this ocean may be briefly described as an irregular trough, having a short and comparatively steep slope on the west, but terminating in a submarine plateau, extending from Bombay to Penang on the east. The ocean has not as yet been properly explored, but soundings in connection with submarine telegraphy give about 2200 fathoms as the maximum in the northern part; other parts are believed to be much deeper than this.

83. **Remarkable Inequalities.**—We have already noticed the remarkable ridges which divide the bed of the Atlantic. The Mediterranean is also divided by a ridge from Sicily to Africa; and while the eastern basin averages no more than 2000 feet, the western is as deep as 5000 feet or more, some say 9000 feet. The British Islands and France, again, rise upon a submarine plateau, which is nowhere more than 600 feet below the surface, but a short distance west of Ireland it drops down to 2000 feet. If we may credit the depths given, we have a striking instance of inequality in the Straits of

Gibraltar. Opposite Cape Trafalgar the depth is 360 feet, and in the narrowest part of the strait a depth of from 960 to 3000 feet was sounded; while between Gibraltar and Ceuta a depth of 6000 feet was reported, and farther east the depth was believed to be still greater. This would indicate the existence of a submarine precipice not far short of 6000 feet in height. Other remarkable irregularities have been observed, but, as we have said before, the bed of the ocean as a whole is characterised by extreme evenness and regularity, the elevations being in fact gentle undulations.

84. **Temperature.**—Until comparatively recent years but little was known as to the temperature of the ocean, the observations formerly made not being sufficiently extensive, nor indeed fully reliable, to enable geographers to estimate rightly the various conditions of climate, etc. largely dependent upon this important factor in the economy of nature. The general temperature of bodies being in a direct ratio to their capacity for heat, let us for a moment consider water as regards its specific heat. This is found to be higher than that of any other known substance. For instance, it requires 33 times as much heat to raise a given quantity of water to a certain degree as it does to raise the same quantity of mercury to the same degree; and conversely, if the temperature of equal amounts of water and mercury be lowered 1°, 33 times as much heat will be given off by the water as by the mercury. Notwithstanding that water has the highest specific heat, it is a bad conductor of heat (conductivity not being necessarily dependent on specific heat),—that is, the heat gained in one part is not transferred from atom to atom, as in a piece of iron heated at one end, but the mass

is made of equal temperature throughout by convection,—that is, by the actual transference of the heated particles to other positions, their places being occupied by the colder particles, which are in turn heated and transferred elsewhere, and so on until the whole mass is uniformly heated. The heating, therefore, of large masses of water is a slow process, both from the greater amount of heat required and from the distribution of that heat by convection only. In comparison with the land, we may, generally speaking, say that it requires four times as much heat to raise water to the same temperature as land; the land, therefore, receives heat and parts with it more readily than water does, and *vice versa* the sea is not so easily warmed, nor on the other hand so readily cooled, as the land. The consequence is, that a certain area of water retains much more heat than an equal extent of land. The sea, therefore, as regards temperature, is more equable than the land—that is, the difference between the surface temperature of the sea in summer and winter is not so great as on the adjoining land, being higher than the land in winter, and lower than it in summer. The effect of this comparative invariability in comparison with the land has a decided effect upon climate. Thus it is well known that maritime countries have not the extremes of heat and cold to which inland countries are subject. (The influence of the sea on climate will be fully explained in a subsequent article.) As regards the general surface temperature of the ocean, we may say that it depends upon the amount of solar heat received, and also in a greater or less degree upon the prevailing currents. Horizontally the temperature diminishes gradually from the equatorial regions to the poles;

while vertically the decrease is irregular, although some affirm that at very great depths the ocean preserves a uniform mean temperature of 39½° F. Recent observations seem to disprove this, it being found that the lowest strata of deep-sea water has a temperature as low as the freezing point of fresh water, or even below it. The effect of the sun's heat does not penetrate beyond a depth of about 100 fathoms, or that of the great currents below 500 fathoms; below this the temperature diminishes as the depth increases, the lowest strata of water in all the great oceans, except in those cases just mentioned, even at the equator, being at if not below the freezing point. But we must caution the student against the supposition that any general statement can be made as regards either the surface or vertical temperature of the ocean, or indeed of any considerable body of water, the variations even in parts closely connected being so marked that an elementary knowledge of this important subject can only be obtained by a careful study of those portions that have been fully explored. Our limited space will not allow us to do more than give a few of the most reliable recent observations. (The longitude of the stations where the following observations were taken is not given by Mr. Prestwich, who collected and arranged them.) *In the Atlantic*—latitude, 42° N.: at the surface, 17·7° C.; bottom (4688 feet), 6·6° C. Latitude, 29° N.: surface, 24·4° C.; bottom (8399 feet), 6·1° C. Latitude, 4°25′ N.: surface, 27·1° C.; bottom (6037 feet), 5·9° C. Latitude 15°·3′S.: surface, 25° C.; bottom (7200 feet), 4·1° C. Latitude, 25°10′ S.: surface, 19·6° C.; bottom (5315 feet), 3·1° C. The rate of decrease of temperature downwards may be seen from the following station, 2 miles north of equator, long. 22°16′ W. At the surface (the air being 22·6° C.), 27·2° C.; at 300 fathoms, 6·44° C.; at 400 fathoms, 5° C.; at 1000 fathoms, 3·3° C.; at 2000 fathoms, 1·64° C. *In the Pacific*—latitude, 51° 34′ N.: surface, 11·7° C.; bottom (5741 feet), 2·5° C. Latitude, 28°52′ N.: surface, 25·5° C.; bottom (3600 feet), 9° C. Equator: surface, 30° C.; bottom (6000 feet), 2·5° C. Latitude, 43°47′ S.: surface, 7·5° C.; bottom (6400 feet), 2·3° C. *In the Indian Ocean* (Bombay plateau)—surface, 26·1° C.; bottom (51 fathoms), 25·8° C. *Arabian Sea*—surface, 23·8° C.; bottom (2170 fathoms), 0·83° C. *In the Mediterranean*—surface, 80° F. in summer, 54° F. in winter; below 100 fathoms down to 1000 or 1800 fathoms, constant temperature of 54° F. *Gulf of Mexico*—surface, 86° or 88° F. *China Sea*—surface, 84° F.; 200 fathoms, 50·5° F.; bottom (1550 fathoms), 37° F. *Sulu Sea*—surface, 84° F.; at 200 fathoms, 50·5° F.; bottom (1780 fathoms), 50·5° F.

85. **Density.**—Sea water contains a percentage of from 3·5 to 4·5 of solid saline matters, and is therefore of greater density than absolutely pure water. The mean specific gravity of sea water (pure fresh water at 62° F. being taken as 1) has been found to be 1·0275. The difference at various places is not very considerable. Thus the specific gravity of water in the North Pacific is 1·0254; in the Indian Ocean, 1·0263; in the northern part of the Red Sea, 1·0279; under the equator, 1·0217. As we have said before when treating of the composition of sea water, the water at the surface is generally fresher than that below; and the salter the water is, the greater will be its specific gravity. The greater the depth, therefore, the denser the water from the excess of salinity.

But besides this, water is slightly compressible, and at 1000 fathoms (6000 feet) is supposed to be compressed to the extent of $\frac{1}{340}$th of its bulk. According to this calculation, at one mile the pressure would be over 2000 pounds on the square inch (equal to 160 atmospheres), while at 4000 fathoms the pressure would be equal to that of 750 atmospheres. Notwithstanding the regular increase of pressure from the surface downwards, it has been found that the density does not increase at a uniform rate, but that, in some cases at least, water at considerable depths has been found of less density than that at the surface. For instance, Sir W. Thomson found at 54° 28′ N. lat. and 11° 44′ W. long. the specific gravity to be 1·028; while at the bottom, at a depth of 8550 feet, it was 1·0269, thus showing a difference of 0·0011. The greater density of the surface water, in this case, was evidently due to a greater degree of saltness, consequent on excessive evaporation.

The *maximum density* of fresh water is at 4° C. or 39·2° F. If it is cooled below this, it expands until it reaches the freezing point, 32° F. or 0° C. Salt water, on the contrary, does not expand until it reaches the freezing point, which is thus the point of its maximum density also. This point is several degrees lower than that of fresh water, consequently sea water does not freeze so readily; and while the freezing point of fresh water is 32° F. or 0° C., that of disturbed salt water is −2·6° C. or 27·2° F., or, if undisturbed, −3·67° C. or 25·4° F.

86. **Movements of Water.**—In the article on the composition of sea water, attention was directed to the remarkable uniformity in the composition of sea water; and the difference in the proportion of saline ingredients in the waters of equatorial

and polar seas, and in that at the surface and that at great depths, was shown to be very slight. This uniformity in composition is due, in the first place, to the great divisibility of matter, as we showed in the first chapter of this work. By reason of this property, easily-dissolved solid matters, such as the saline ingredients found in sea water, are divided and subdivided to such an extent as to be equally distributed throughout the whole mass. But the dissolving power of water varies as its temperature; warm water dissolving more than cold, or, in other words, a certain amount of warm water will hold more saline or other ingredients in solution than an equal amount of cold water. We should therefore expect to find a marked difference as regards salinity between the warm tropical waters and those of the colder northern seas. That there is a difference we have already seen, but it is not so marked as might be expected. The reason is, that the general uniformity in the composition of the waters of the ocean is preserved by those incessant movements to which it is subject, and by means of which its waters are mingled together so thoroughly, that, supposing an increase of saltness to take place from any cause in any part of it, the excess is immediately distributed to the surrounding water, until nearly absolute uniformity is reached; or, *vice versa*, if from any cause the sea water is rendered fresher, the abstraction of a portion of the saline ingredients of the surrounding salter water immediately commences, and if nothing occurred to disturb the operation, a general uniformity as regards saltness would be the ultimate result. The movements which we referred to are produced by various causes, operating either at the surface or throughout the whole mass, or are entirely extra-terrestrial. To the first we refer the phenomena of *waves*, as due to the action of the wind; to the second *ocean-currents*, as due to the unequal temperatures and densities of various parts of the ocean; and to the third the *tides*, as due to the influence of the sun and moon, but principally the latter. That these various movements are most important factors in the economy of nature, we all admit, and it remains to us to see how and in what direction their influence is exerted, and with what results.

87. **Waves.**—Let us commence with the simplest movements to which all considerable bodies of water are subject, viz. waves; and first let us see how a wave is produced. The cohesion of the particles of water, and indeed of all other liquids, being limited, they therefore obey the slightest impulse; but, owing to the small condensability of water, displacement in any part is always, and from the reason stated, necessarily accompanied by an occupation of an equal portion of new space. For example, if we fill a cup full of water and then put a solid body in the water, the water will run over—that is, the displacement of the particles of water by the introduction of the solid body is attended by the occupation of new space outside the cup by as much water as was displaced by the solid. It is important to understand this point, as the phenomena of waves are entirely dependent upon this limited compressibility and cohesion of water. If, therefore, from any cause the water is depressed at one point, this depression is always accompanied by a corresponding elevation immediately beyond this point. A sudden blast of wind, for instance, strikes against the surface of the water at a certain angle. What is the result? The equilibrium of the water is disturbed, depression occurring at the

point of impact, producing, as we have said, a corresponding rise beyond. If the wind continue blowing, similar depressions and corresponding elevations of the water are produced, thus giving rise to a series of undulations, or up and down motion of the water. Such undulations are called *waves*. From this explanation it is evident that the depression and corresponding rise are entirely dependent on the force of the wind and the angle at which it impinges on the surface. When these are small, the undulations are mere ripples; but if the force and velocity of the wind increase, larger undulations are produced, attaining sometimes a height of 30 or 60 feet from crest to trough. It must be remembered that, so long as the wave is unbroken, there is no forward motion of the displaced particles constituting the wave, but the undulation is simply a rise and fall of the water in nearly, if not quite, a vertical direction. When, however, an undulation reaches shallow water, its lower portion is checked by contact with the bottom, while its upper part advances rapidly and breaks into a mass of curling foam. If any permanent obstacle, such as a fringing reef, etc., lie in the path of the advancing waves, a constant mass of broken water or *surf* is the result, through which it is often dangerous if not quite impossible to pass. Wind waves do not disturb the water to any very considerable depths, at least in the open sea, and during the most violent storms it is supposed that the motion ceases at a depth of about 300 feet. Tidal waves, on the contrary, are the result of a disturbance of the whole mass by the attracting influence of the sun and moon. Both tidal and wind waves, at least in the open ocean, agree in being simply undulations or risings and fallings of the water in a nearly vertical direction, and in which the particles are not carried forward, but simply oscillate with a certain amplitude, and then return to their normal position, or nearly so. In what are termed *waves of translation*, on the contrary, the whole mass of the wave is carried forward with great rapidity, as when a tidal wave enters a narrow and shallow opening, in which the advancing mass, being contracted in width by the narrowness of the channel, rises to a height of 50, 60, or even 80 feet, and sweeps onwards in an unbroken wall of water, often with a great velocity, to a considerable distance. As regards magnitude, wind waves vary from the smallest ripples under a gentle breeze to mighty waves of 30 and 40 feet high, driven on with great velocity by a heavy gale. The largest waves known occur off the Cape of Good Hope during a north-west gale, when they attain a height of 40 feet, and those off Cape Horn often 30 feet high. In the North Atlantic wind waves vary from 20 to 25 feet, but in the Bay of Biscay waves of 36 feet have been observed. In the British seas they rarely exceed 8 or 10 feet. It is, of course, difficult to determine accurately the magnitude of waves, but from the numbers given it will be seen that the expressions 'mountains high,' etc. are based upon greatly exaggerated notions of their size, induced no doubt by the grandeur and apparent vastness of the moving masses of water. But waves even of 8 or 10 feet, when they impinge directly against an obstacle, exert an enormous pressure; and their abrading and transporting power is almost incredible, were it not abundantly proved by breaches made in sea-walls, and in the displacement of huge blocks, in some cases weighing 20, 30, or even 40 tons. Although wind waves rarely, if ever, exceed 40 feet, earthquake waves, produced by the concussion or shock imparted to the water by the sudden vertical displacement of the ocean floor, attain much greater heights. Thus, during the Lisbon earthquake of 1755, a wave supposed to be 80 feet high rolled on the Portuguese coast, and similarly huge waves have accompanied other violent earthquakes. The deep undulations or heavings of the sea during a violent storm are continued long after the wind has abated, forming what is known as a *ground swell.* As regards the *velocity* of waves, we may, generally speaking, say that the velocity depends primarily upon the force and velocity of the wind; but this is modified by the depth of the water which the wave traverses. In fact, a certain definite relation has been found to exist between the velocity of a wave and its magnitude and the depth of the water over which it passes, so that, given the depth and magnitude of the wave, its rate of movement may be easily calculated; or *vice versa*, given the rate of movement and depth of water, the height or magnitude of the wave may be deduced. The power and functions of waves, geologically considered, are points of such importance that we must reserve them for a special article.

88. **Tides.**—In the second chapter of this treatise we explained that species of attraction termed gravitation or gravity, which we defined as the mutual attraction that exists between masses of matter irrespective of their nature or quantity; and that all particles, presumably of the same weight, have equal attractive power, and therefore the greater number of gravitating particles, or, in other words, the greater the mass, the greater the total power of attraction. We observed further,

that the attractive force diminishes in proportion as the distance between the mutually-attracting bodies increases. These fundamental truths constitute the laws of gravitation, which we thus briefly stated:—*First*, that the force of attraction between two bodies is in a direct ratio to their mass; and *secondly*, that this force, as all other radiant forces, is in an inverse ratio to the square of the distance.

This being the case, the earth attracts and is attracted by the sun and all planetary bodies in proportion to their mass and distance. Of all the heavenly bodies, the moon is the nearest to the earth; and although, from its small bulk as compared with the sun, its total attractive force on the earth as a whole is much less than that of the sun, yet, owing to its greater proximity, the *difference* between its attraction on different parts of the earth is much greater. And it is to this difference in the attraction of the sun and moon, principally the latter, upon different parts of the earth that the periodical rising and falling of the waters, known as the *tides*, are due. If the earth were solid externally as well as internally, the attractive power of the sun and moon would affect the earth as a whole only, for, from its rigidity, no particular portion of it could be influenced separately. But we know that nearly two-thirds of the earth's surface is covered by water, which, from its slight cohesiveness, yields to any disturbing influences much more readily than the solid crust. If the globe were a perfectly smooth sphere covered by water and undisturbed by any external influences, the water acted upon by terrestrial gravity only, or that force by which everything on the earth's surface tends to fall towards the earth's centre, would be attracted equally at all points, and thus would cover the earth's surface uniformly, forming an exact spherical surface. But disturbing influences are present in attractive forces of the sun and moon. The sun, as we have said, on account of its immense mass, attracts the earth *as a whole* much more powerfully than the moon does; but the moon is much nearer, and, as as the force of gravitation is in an inverse ratio to the distance, it will be evident that the *difference* between the moon's attraction on opposite sides of the earth will be much greater than the difference between the sun's attraction at the same points, the proportion in round numbers being as 5 is to 2. The moon, therefore, plays a more important part than the sun in producing the phenomena of the tides. For the sake of simplicity and clearness, let us for a moment ignore the sun's attractive force, and consider that of the moon only. Let us suppose the globe to be uniformly covered with water. (Instead of giving the diagram in full, as usual, we think it will be better for the student to draw one for himself from the directions given.) From C as centre, and with a radius of, say, half an inch, describe a circle to represent the globe. From C again as centre, with a slightly larger radius, describe another circle. The ring thus formed will represent our supposition of a globe uniformly covered with water. At a distance of, say, 1½ inches from the point C, draw a smaller circle M to represent the moon. Join MC by a dotted line, cutting one side of the ring in S^1, and produce MC to *m*, cutting the opposite side in S^2. If the moon now acts upon the earth in the direction M*m*, and as the force of attraction diminishes as the square of the distance, her attraction will be greater at S^1 than at C, the centre of the earth, and much greater at C than at S^2, on the opposite side of the earth. What is the result? The water at S^1 gradually rises in obedience to the moon's attraction until it is at a considerably higher level than before, and therefore the distance between S^1 and C is increased. Again, the moon attracts the earth at both C and S^2, but C being nearer, and the attracting force diminishing as the square of the distance, it operates more powerfully at C than at S^2, therefore the distance between C and S^2 is also increased. The consequence is, that the water at S^2 is left behind, as it were, and bulges out exactly like that at S^1, though not in the same degree, owing to the attraction decreasing in power as the distance increases, and therefore the distance from S^1 to C will be somewhat greater than that from S^2 to C. Hence two protuberances are formed in the line of the moon's attraction on the opposite sides of the earth, the bulging out on the side next the moon being due to the direct elevating power of the moon's attraction, while that on the opposite side is due to the *difference* in the force of attraction at the centre and at the surface farthest from the moon. But this bulging out at S^1 and S^2 will necessarily be accompanied by a corresponding sinking in other places, the water being, as it were, drawn away in the direction S^1 and S^2. And so we find that while the surface of the water at S^1 and S^2 respectively is higher than before, or, in other words, at a greater distance from C, the distance from the surface of the water to the centre at points midway between S^1 and S^2—that is, at S^3 and S^4—is less. Hence we say it is high water or *flood* at S^1 and S^2, and low water or *ebb* at S^3 and S^4. This may be shown by a dotted line outside the outer circle at S^1 and S^2, and inside it at S^3 and S^4. Now, if the earth and moon were immoveable, the flood and ebb would be always at the same points; but as the earth rotates on its axis, every part of its surface is successively brought under the direct influence of the moon, whose appreciable result, however, is confined to the ocean alone, the waters of which rise when directly under the moon, and sink to their former level when not so. A great undulation or *tidal wave* is thus produced, which, owing to the earth's rotation from west to east, moves round the globe in a contrary direction, from east to west, and therefore the farther east any place is, the earlier will the tides occur at that place. As regards the sun, the earth rotates once in twenty-four hours—that is, supposing the sun to be in the zenith of, or vertical to, any given place, twenty-four hours will elapse before it is again vertical to the same place. But the sun, relatively to the earth, is fixed and immoveable. The moon, however, is different, as it moves round the earth at the rate of about 13° eastward daily. As regards the moon, then, the earth must make rather more than a complete rotation before the moon is brought again to the same meridian; and thus, while the solar day is twenty-four hours, the lunar day is twenty-four hours fifty minutes twenty-eight seconds. And as the moon is the principal agent in producing the tides, it will be at once seen that the tides at any given place will be about fifty minutes later each day than the day before, that time being necessary to bring the moon again to the zenith of, or vertical to, that place. It must, however, be remembered that the moon's attraction is more or less gradually exerted, so that it is not high water at precisely the time when the moon is vertical to a given place, but at about an hour after, the attracting force culminating, as it were, after the moon had passed over the meridian. Thus far we have ignored the part played by the sun in producing or modifying the phenomena of the tides. The sun, although at a great distance, is of such magnitude that its attraction on the earth *as a whole* is much greater than the smaller moon, although the latter is so very much nearer the earth. But the tides are due, not primarily to the attraction of either the sun and the moon on the earth as a whole, but to the *difference* in the attracting force at the centre and opposite sides of the earth. We have already shown how the protuberance on each side in the line of the moon's action is produced, and the difference in the moon's attraction on the side of the earth nearest and on that farthest from it has been computed to be not less than one-thirtieth of its attraction on the earth as a whole. The difference in the sun's attraction on the opposite sides of the earth, however, is only one twelve-thousandth part of its total attraction. Now the moon's attractive force is to that of the sun as 1 is to 195, and therefore the difference in the moon's attraction on the opposite sides of the earth in proportion to the sun's attraction will be thirty times one one-hundred-and-ninety-fifth part, or one five-thousand-eight-hundred-and-fiftieth part. The difference, then, in the attraction of the sun and moon on the opposite sides of the earth may be said to be as one twelve-thousandth part is to one five-thousand-eight-hundred-and-fiftieth, or in round numbers as 2 to 5, and therefore the moon's tide-producing influence is more than twice that of the sun; or supposing the earth to be uniformly covered with water, and the sun and moon to act separately, the tide produced by the sun would be twenty-three inches, while that produced by the moon would be fifty-three inches. But though the sun's influence as an independent tide-producer is thus limited, yet it affects the lunar tides considerably; for at new and full moon the sun is in the same line as the moon and the earth, or in conjunction; its influence, then, is added to that of the moon, so that the water is attracted much more strongly than by the moon separately, consequently twice every month the tides are greater than usual, forming what are termed *spring tides.* But when the moon is in her first and last quarters, the sun's attraction is exerted at right angles to that of the moon; and thus the rising of the water on the side of the earth next to the moon, and on that opposite, is in a measure counteracted by the sun's attraction acting on the points midway between those acted upon by the moon, and consequently the tides formed are produced by the difference in the attractive forces of the sun and the moon; so that twice each month the tides are less than usual, and are then called *neap tides.* As we remarked before, the motion imparted to the water does not cease immediately on the withdrawal of the sun's or moon's *direct* influence, but both spring and neap tides happen, not on the exact day of the change or full moon, but a day or two after. This is somewhat analogous to the ground swell, or the agitation or heaving of the sea long after the storm has subsided; and supposing the sun and moon's attraction to be suddenly diverted from the earth, the effect on the tides would not be appreciable for some time after. Of course, when the moon is nearest to the earth, or in *perigee*, the tides are higher than when she is farthest from the earth, or in *apogee*, the spring tides being greater before the vernal and after the autumnal equinox than at any other time. We may also observe that the mean height of the tides seems to have slightly increased of late years, proving, without the shadow of a doubt, that the mean distance of the earth and the moon must be gradually decreasing, and, unless counteracted in some way, must in time necessarily produce great changes in the present distribution of land and water.

89. **The Tidal Wave.**—Having thus endeavoured to give the student a correct idea as to the cause, or rather causes, of the tides, let us proceed to consider more minutely the course of the tidal wave. For the sake of clearness, we based our explanations in the last article on the supposition that the earth was a globe uniformly covered with water. If this were the case, the tidal wave would flow regularly every day from *east* to *west* round the globe, being highest in the belt comprised within the parallels of 28½° N. and 28½ S. lat., and decreasing gradually northwards and southwards towards the poles. But this theoretically simple and regular motion is broken by the intervention of the land masses, the only considerable portion of water comparatively free and open being the great Southern Ocean, in which alone the tidal wave preserves its primary and normal direction, from east to west, moving across it at a rate of 1000 miles an hour. We might indeed say that the tidal wave receives its primary impulse in this part of the ocean, from whence it is propagated to the Indian and Atlantic Ocean, not, it must be remembered, by any actual movement or 'translation' of the mass of the

wave: the *form* only moves, not the water itself, at least in the open sea. In narrowing estuaries of tidal rivers or bays, the tidal wave, from being an undulatory vertical motion of the water, becomes a 'wave of translation,' in which the water is carried forward with great velocity. In such a *cul-de-sac* as the Bay of Fundy, the wave rises to a height of 100 or even 120 feet, and in the Bristol Channel as high as 50 feet. Such risings are called *bores*, and in rivers whose estuaries lie in the course of the tidal wave (hence called tidal rivers) the influence of the tide is felt for a considerable distance inland. The bore in the Tsien-tang in China attains a height of 30 feet, and rushes up the river at the rate of 25 miles an hour; that of the Hooghly, about 25 feet high; the Severn, 9 feet. Inland seas, such as the Baltic and Mediterranean, which communicate with the ocean by openings lying transversely to the course of the tidal wave, are thus excluded in a great measure from its influence; and as their size is such that the formation of a separate tide wave, at least of any considerable height, is impossible, such seas may be almost called tideless. The height of the tide in the open ocean is from 3 to 8 feet, increasing in height as the width of the water over which it travels decreases, and attaining its greatest height in bays or inlets lying open to its course, and, becoming narrower and shallower, prevent the wave from spreading, which thus increases in height in proportion to its compression by the form of the land.

What is known as the *establishment of a port* is the determination at that port of 'the actual time of high water on the day when the moon passes the meridian at the same time as the sun,' from which the monthly series of tides may be calculated. If, therefore, the 'establishments' of a number of ports be accurately determined, and their position marked on a map, together with the number indicating the hour of high water in Greenwich mean time, and if all the ports having the same numbers be successively joined by lines, such lines will show the course of the tidal wave, and are called *co-tidal lines.* We are thus enabled to trace the course of the tidal undulation from its origin in the Southern Ocean to its farthest ramification in the north, and thus also its deflection from its normal westerly direction is also clearly seen to be dependent upon the peculiar configuration of the coast. The tidal wave, as we have said, seems to receive its primary impulse in the Southern Ocean, whence it is, as it were, started on its journey round the globe. Let us, then, briefly trace its course from, say, Tasmania. We will suppose it is high water here at noon on, say, Monday. Moving westwards at a gradually more oblique direction to the coast, at five in the afternoon it will be high water off Cape Leeuwin. The wave now bends in into the Indian Ocean, bringing high water off Cape Comorin at midnight, and, still moving west as well, appears off the east coast of Madagascar and Cape Colony at one o'clock on Tuesday morning. It then presses forward into the Atlantic, at first in a generally south-western direction (appearing at the mouths of the Gambia and the La Plata at the same time), until it passes the equator, when it inclines more and more to the north-west, and at noon on Tuesday appears off Newfoundland on the American, and Cape Blanco on the African, side of the Atlantic. Five hours later the wave stretches from the southern coast of Iceland, by the south-western extremity of Ireland and Land's End, to Cape Ushant in France.

The wave now divides into three branches, the larger proceeding up the Atlantic between Iceland and the north-western shores of Europe; a portion of it flows round the Orkneys, bringing high water to Aberdeen at midnight—that is, 36 hours since it started from Tasmania; then, flowing still south, at noon on Wednesday it is high water off the mouth of the Thames. A second branch proceeds up St. George's Channel, after sending an immense wave into the Bristol Channel, and, traversing the Irish Sea northwards, meets the tide coming southwards through the North Channel off Courtown on the north-east coast of Ireland; and as the ebb of the one corresponds with the flow of the other, they neutralize each other at this point. The third branch presses up the narrowing English Channel; and such is the mass of water forced in, that it rises 50 feet above the normal level at St. Malo on the French coast. Pressing still up the Channel, it appears off Dover at eleven in the morning, and at midnight on Tuesday meets that coming down the German Ocean off the mouth of the Thames. But it must be remembered that the latter tide is 12 hours older than the former; and thus, while the latter has taken 48 hours to reach the mouth of the Thames, the former, coming up the shorter route through the English Channel, has taken only 36 hours, and passes Dover 2 hours before the latter is at Aberdeen.

90. **Currents.**—A gust of wind impinging against the surface of the water, at however small an angle, causes, as we have said, the undulations known as waves, in which the water is not carried forward

(except in particular cases, where, owing to the presence of sandbanks, rocks, or other impediments, the undulation is converted into a 'wave of translation'), but simply rises up and falls down in a nearly if not quite vertical direction. The tide wave, again, is simply such an undulation on a large scale, but owing its origin not to the wind, but to the attraction of the sun and moon; so that, both in wind waves and tide waves, there is not, generally speaking, any actual translation of the water from one part of the ocean to another, it being well known that the *form* only moves. Were these the only movements to which the sea is subject, a ship, sailing from one port to another due east, could scarcely fail to reach the 'desired haven' if her head be turned due east and then steered straight on. Instead of sailing right into the port, however, the sailors would most probably find themselves a considerable distance north or south of it, unless, knowing what they had to encounter, they had taken due precautions. The alteration in the ship's course was due not to any alteration in heading the vessel, but was owing to the drifting, scarcely perceptible in the open sea, of the vessel by a northward or southward movement of the water over which she sailed, and which, although her head was kept all along due east, 'drifted' her out of her straight course. Such a movement in the ocean is termed a *current*, and is indeed an actual ocean river, however paradoxical the term may appear. It is therefore of the highest importance, and indeed absolutely necessary, for mariners to know the exact position, direction, and velocity of these currents, so as to enable them to make due allowance for the 'drifting' of the vessel when in the course of a current. Currents, therefore, have been closely observed and duly marked on sailing maps or charts. Some currents are *constant*, flowing in the same direction at all times; others are *periodical*, while others again are *variable*. Sometimes they are distinguished as *deep-sea currents* and *drift currents*, the former being by far the most important, being due to the difference in temperature, density, salinity, etc.; while the latter are, as their name implies, caused by the prevailing winds. It may also be advisable to distinguish between *surface currents* at the surface, and *submarine currents* at some depth, often flowing in a different direction to the former. Before bringing before the student the principal points in the discussion as to the origin of currents, let us notice briefly the principal and better known currents, first premising that ocean currents are named according to the direction *to* which they move; wind currents, on the contrary, being named according to the direction *from* which they come. Thus a northerly current flows *towards* the north, while a northerly wind blows *from* the north.

91. **Principal Currents.**—When speaking of the course of the tidal wave, we commenced at the wide expanse of water encircling the globe called the Southern Ocean, as being that in which it received its primary impulse; and although we cannot institute any analogy in this respect between tide waves and ocean currents, we may for the sake of clearness commence with the same ocean. The *antarctic drift currents* flow northwards into the Pacific, Indian, and Atlantic Oceans, and carry the icebergs of the frozen south polar regions sometimes as far north as the Cape of Good Hope. A large portion of the antarctic drift strikes against the extremity of South America, and divides,—one

branch, the *Cape Horn current*, flowing round Cape Horn and bearing away to the east; while the other branch flows along the western coast of South America, forming the *Chili and Peruvian* or *Humboldt's current.* This current is characterised by a much lower temperature than the ocean through which it flows, being about 10° F. lower for more than 400 miles, and in some places, as off Lima, as much as 20° F. below the adjoining ocean. This striking difference in temperature shows that the cold water of the antarctic regions actually moves some hundreds of miles up the Pacific. This 'cold current,' as it is called, by degrees becomes warmer, and, following the trend of the coast, turns westwards, and in 20° S. lat. merges into the great *equatorial current* of the Pacific, which occupies the whole space between the tropics, and sweeps westwards at the rate of thirty or thirty-five miles a day till it reaches the East Indian Archipelago. A portion of it then curves north, and finally takes a north-easterly direction as the *Japan current*, which may be said to be a modified counterpart of the Gulf Stream in the Atlantic, carrying the heated equatorial waters to Kamtchatka, and even to the Arctic Ocean through Behring Strait; but as the latter is contracted, and the current, besides, being greatly checked by the chain of the Aleutian Islands, the greater portion turns south, following the North American coast and bifurcating off California, one branch curving into the equatorial current, while the other, keeping close to the shore, flows southward into the variable *Mexican current.* The southernmost portion of the Pacific equatorial drift flows south along the Australian coast as the *New South Wales current*, and is finally lost in the antarctic drift. The middle portion of the equatorial current is split up into many branches, which, pressing through the various channels between the East Indian Islands, at last enter the Indian Ocean. The currents in this ocean north of the equator vary with the seasons, being regulated by the monsoons; but the general movement of the water between West Australia and Madagascar is westward, and gives rise to the *Mozambique current*, passing between Madagascar and the African continent. This current is joined by the remaining portion of the equatorial drift, and flows southwest towards the Cape of Good Hope as the *Agulhas* or *Cape current*, a portion of which only sets in into the Atlantic, the rest being checked and turned back by an easterly inflow from the Atlantic to the Indian Ocean. The latter forms the important counter current of the Indian Ocean, moving at the rate of about 50 miles a day in the direct route to Australia. That portion of the Cape current still holding its way, turns up the African coast as the *South Atlantic current*, and merges into the great *equatorial current* of the Atlantic, which, flowing across the Atlantic to the South American continent, is broken into two streams by the wedge-shaped coast against which it strikes. The southern branch, the *Brazilian current*, follows the trend of the coast at some distance out, but, becoming slower, and being greatly checked by the La Plata cross stream, ultimately disappears as a distinct current, and is merged into the *southern connecting current* of the Atlantic. The northern branch of the equatorial current turns in a north-westerly direction from Cape St. Roque, and flows towards the West Indian Islands as the *Guiana current*, ultimately pressing through various channels into the Caribbean Sea, and, skirting the coast of Guatemala, enters the Gulf of Mexico through the Straits of Yucatan. A portion of it, however, is deflected towards the Cuban coast, and trends south by Jamaica, finally merging into the main northerly stream. The accumulated waters thus forced into the Gulf of Mexico have, during their tropical journey, acquired a much higher temperature and greater degree of salinity than those of the contiguous ocean. Being confined within the nearly land-locked Mexican Gulf, the current gains in force in proportion as it is pent up, as it were; and after making the circuit of the Gulf, the full current rushes through the narrow Straits of Florida, and becomes the celebrated *Gulf Stream* of the Atlantic, —one of the most, if not the most, important constant currents of the globe, carrying the warm waters of the tropics far north, and effectually preventing the cold surface currents and icebergs of the Arctic Ocean from reaching so far south as they would had there been no such obstacle to bar their progress. The Gulf Stream itself, on leaving the Straits of Florida, has a velocity of 4 miles an hour, and follows the bend of the North American coast as far as Cape Hatteras, whence it curves into the Atlantic, and is now supposed to cease at about 45° N. lat., although formerly geographers asserted that it held on its way to the north-east, extending its thermal influence as far as the British and Scandinavian coasts, if not to Spitzbergen and Nova Zembla. The warmer waters that bathe the coasts of these islands and Norway are now declared to be a part of a northerly surface flow from the equatorial to the polar regions. The waters of the latter, being contracted by cold, lower their normal level, while those of the former, being expanded by heat, rise somewhat above the general level; and as by the force of gravitation water always endeavours to preserve a uniform level, the higher equatorial waters are said to flow down the slope thus produced to restore the uniformity in level disturbed by the contraction of the polar waters. Whether this is so or not is the subject of much discussion, and until we have a more detailed knowledge of the subject than at present, must remain an open question. For the present, however, we must take the actual facts and present them to the student without comment. This much is certain, that while there is a north-easterly tendency in the waters between Iceland and the British and Norwegian coasts, there is a compensating indraught current from the Arctic, flowing through the channel between Iceland and Greenland, which, on reaching latitudes of a higher velocity of rotation, is deflected towards the south-west, and off Cape Farewell is joined by the *Davis Strait current* from Baffin's Bay. The united streams then skirt the coast as the *Labrador current*, and, bending round Newfoundland, flow along the coast, and, striking against the north-easterly Gulf Stream, form the 'cold wall' on the northern side of that current. Being heavier than the warmer waters now surrounding it, the arctic current sinks below the Gulf Stream, and actually enters the Gulf of Mexico through the channel of Florida as a submarine current, thus replacing the water carried north by the Gulf Stream, and also modifying the extremely high temperature which would otherwise result from the penting up of such a mass of warm water in the Mexican Gulf. Both the equatorial current and the Gulf Stream curve round again to the south, the centre of the curve being occupied by still water covered with the *Sargassum bacciferum* and other sea-weeds, and therefore called the *Sargasso Sea*. This counter current curves by the Portuguese coast, and a portion enters the Mediterranean through the Straits of Gibraltar; while the rest, closely hugging the African coast, continues its way south, merging into the *Guinea current*, which runs side by side with, but in a contrary direction to, the great equatorial current, towards which it curves and which it ultimately joins. Having thus sketched, necessarily very briefly, the principal constant currents of the great oceans, we will for a moment advert to those of the more important inland seas. And first the *Mediterranean currents*. This nearly land-locked sea is subject to active evaporation; so much so, indeed, that a much greater amount is evaporated than is supplied by the inflow from rivers. This, if not compensated in some way, would in a year result in the lowering of the level as much as 50 inches below that of the Atlantic. To restore the level, a surface current sets in from the Atlantic through the Straits, and as the evaporation is constant, the surface current is also constant, although sometimes slightly modified by winds or tides. But as the water of the Mediterranean is salter and denser than that of the Atlantic, there is an outflow from the former to the latter as an under current—sometimes as side currents flowing *into*, while the central current flows *from*, the Atlantic. As regards the *Baltic currents*, this sea not being subject to any active evaporation, the inflow from rivers is greater than the evaporation, consequently there exists an outward surface current through the Sound, while the equilibrium is in some measure restored by an inflowing under current. In the *Red Sea*, again, as in the Mediterranean, we have an instance of excessive evaporation, and no inflow whatever from rivers. A surface current, therefore, through the Straits of Bab-el-Mandeb, replaces the enormous loss by evaporation, which is such that, were there no such supply, the level would be lowered at least 20 feet annually.

92. **Temperature and Velocity of Ocean Currents.**—Both wind and tide waves produce no change in the waters of the ocean beyond that of form, and even that is merely temporary. They do not affect the temperature of the water in the least, nor, except in extreme cases, do they produce change of position. Ocean currents, on the contrary, flow over immense areas, and carry the waters of one ocean into that of another; and thus the very drops of water melted from an antarctic iceberg may pass through the Pacific, Indian, and Atlantic Oceans, and be ultimately congealed again off the shores of Greenland. As ocean currents, then, transport the waters of one region to another, the *temperature* of ocean currents will depend on that of the region whence they flow; while their *velocity* depends on several causes, such as the conformation of the coasts between which they flow, the depth of the water over which they pass, etc. Thus the Peruvian current is but the northward prolongation of the antarctic drift, and shows its origin by its coldness, being about 14° colder than the overlying air, and 10° colder than the ocean in the same latitude. The Atlantic equatorial current has a velocity of 20 to 60 miles a day, and an average temperature of 75° F., or about 6° higher than that of the water on either side. The Guiana current has an initial velocity of about 30 miles a day, but on entering the Caribbean Sea this is increased to fully 80 miles. The current in the Mexican Gulf has a

temperature of about 7° or 8° higher than that of the Atlantic at the same latitude, and rushes out of the Gulf through the Straits of Florida at a velocity of 120 miles a day, with a temperature of 86° F. In mid-ocean the Gulf Stream still preserves a temperature of 8° or 10° higher than that of the ocean through which it flows; while off Newfoundland, in winter, the difference is sometimes as much as 30° F. The temperature of the Gulf Stream, however, does not decrease regularly from its commencement to its termination about 45° N. lat., but alternate bands of colder and warmer water are found: the cooler bands are supposed to mark the deeper portions of the ocean. The Mozambique current flows towards the Cape with a velocity of about 70 miles a day, and with a temperature of about 8° above that of the open ocean in the same latitude. We may also notice that both the arctic and antarctic drift currents move very slowly in comparison with the other great currents, scarcely ever exceeding 15 miles per diem. The surface current from the Atlantic into the Mediterranean sometimes attains a velocity of 80 miles a day, while the outward current from the Black Sea moves at the rate of about 25 miles daily. The inflow through the Straits of Bab-el-Mandeb into the Red Sea is at the rate of from 30 to 40 miles a day. Generally, then, we may say that ocean currents have a velocity of less than a mile an hour, and that their initial temperature depends upon that of the region in which they had their origin, and that they traverse, in some cases, thousands of miles before their temperature is raised or lowered to that of the ocean through which they flow.

93. **Causes of Ocean Currents—General Oceanic**

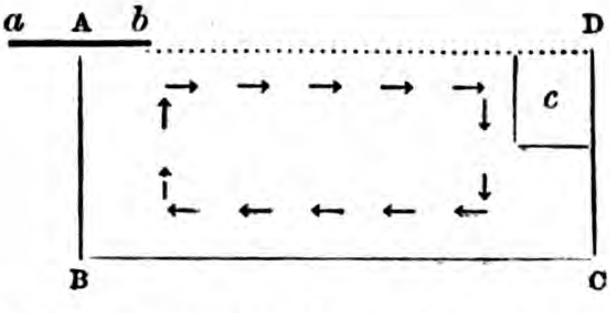
Circulation.—There is, even at the present time, great diversity of opinion as to the causes of oceanic currents, some attributing them to the influence of the winds—'not the prevailing winds alone, but the combined action of all the prevailing winds of the globe, regarded as one system of circulation.' Others, again, affirm that oceanic currents are primarily due to the difference in temperature and density in the equatorial and polar seas. Others, again, assert that the theory of a general oceanic circulation, depending upon differences of specific gravity, is entirely without foundation, and that these movements are simply the result of an excess of evaporation over precipitation in the northern portion of the land hemisphere, and the excess of precipitation over evaporation in the middle and southern part of the water hemisphere. It remains to us to give the principal arguments in favour of or against these theories, necessarily very briefly in a small work of this kind, but, as we hope, amply sufficient to excite in the thoughtful student an earnest desire to become more acquainted with the researches of eminent geographers on this interesting subject. But first of all it may be advisable for us to consider for a moment a few of the principal terms used; for unless we know their exact import, many passages will appear obscure and meaningless, and, it may be, the very passages upon which the argument is based. As we proceed we shall have occasion to use the terms *vertical* and *horizontal* circulation. Let us see what is the exact meaning of these terms. In a few words we may define the *vertical circulation* of the waters of the ocean as the sum total of all those movements of the water which depend upon differences in temperature and density, and which affect the whole mass of the ocean from the surface to the bottom. The term *horizontal circulation*, on the contrary, is confined to those movements at the surface which are due to the agency of the prevailing winds. Associated with the latter term is that of *drift currents*, which are the agents, as it were, of the general horizontal circulation; while in conjunction with the former is the term *deep sea* or *stream currents*, which are presumed to be the acting agents in the general vertical circulation of the waters of the ocean. We have already noticed the distinction between a *marine* current at the surface and a *submarine* or under current, and also between a *current* proceeding in a certain direction and a *counter current* flowing from a contrary direction. Having thus gained a clear notion of the terms used in the discussion, we are in a position to proceed with the consideration of the several theories advanced to explain the origin and causes of the various movements of the waters of the ocean,—movements which, whether we consider them from a climatal or commercial point of view, are among the most important natural agencies. And first of all, as regards the notion formerly prevalent, and still, it may be, lurking in the minds of many students not properly informed, viz. that one great cause of ocean currents is the *revolution of the earth about its axis*—that is, that the motion of the earth from west to east is the cause of a contrary motion of the waters of the globe from east to west. The inconsistency and fallacy of such a supposition is at once seen if closely considered. For if the earth's rotation be the cause of currents, and if the velocity of rotation diminishes in a certain proportion as we advance from the equator to either pole, a proportionate decrease in the velocity of currents as we go northwards or southwards from the equatorial regions would be the result. And further, as the earth's rotation is from east to west in all latitudes, there would necessarily be a general movement of the waters of the ocean from east to west in all latitudes likewise. Is this the case? No; for we have just seen, while enumerating the principal currents, that this westward tendency of the surface waters of the ocean is apparent in the tropics only, and that as we proceed north or south they flow in entirely different directions. Again, if this theory be true, the difference in velocity of rotation at different latitudes would produce a corresponding difference in the velocity of currents. For instance, if a westerly current of 20 miles a day be produced at the equator where the velocity is 1000 miles an hour, we should expect to find a current of 10 miles a day at a latitude north or south where the velocity is half that at the equator; but no such proportionate decrease in the velocity of currents is anywhere observable, and we are therefore driven to the conclusion that the earth's rotation cannot be included as the prime cause, or even as one of the causes, of oceanic currents. But although not a motive power in oceanic circulation, the earth's rotation exercises an undoubted influence on the *direction* of currents, tending to deflect them from right to left in the northern hemisphere, but on the contrary from left to right in the southern. Many examples of this influence might be given; one must suffice. In the Adriatic Sea the inflowing current from the Mediterranean moves along its eastern shores, while the outflowing counter current presses against its western shores. The earth's rotation, then, does not produce currents, but simply modifies their direction,—such modification, however, being slight, and in many instances entirely counteracted by the prevailing wind currents.

Let us now revert to the theory, so ably advocated by Mr. Croll in the *Philosophical Magazine*, viz. that oceanic currents are due to the action of winds, or, in other words, that the general system of oceanic circulation is produced, 'not by the trade winds alone, nor by the prevailing winds proper alone, but by the combined action of all the prevailing winds of the globe regarded as one system of circulation.'

The gist of Mr. Croll's arguments, and their application to particular cases, may be thus summed up:—The direction of the main currents of the globe and that of the prevailing winds agree exactly. This agreement in direction of the current and wind systems of the globe, he thinks, is a convincing proof of the truth of his theory. The Gulf Stream follows the path of the prevailing winds, and, like the wind, bifurcates in mid-Atlantic, one branch passing north-east, the other south-east, in exactly the same direction as the prevailing winds. Again, the antarctic drift current between 140° and 160° W. long., instead of being deflected to the left by the increased velocity of rotation, turns to the right under the influence of the westerly winds, flowing eastwards towards South America. We have seen that, in stating his theory, Mr. Croll does not refer the results to the action of the trade winds alone, nor even to the prevailing winds proper alone, but to the resultant of all winds. This limitation was doubtless intended to remove the objections which would be immediately advanced against the wind theory being accepted, at least in its entirety, based on the fact that many currents flow in exactly opposite directions to those of the prevailing winds blowing over the space they traverse. For instance, the north-east trade winds are said, even by Dr. Carpenter, to be the *primum mobile* of the Gulf Stream, but it is a matter of doubt whether they are powerful or constant enough to produce a current of such magnitude, velocity, and persistency. From Captain Maury's carefully-conducted investigations, we learn that the average number of days during the year that the north-east trade winds of the Atlantic act upon the water is 111 days out of 366—that is, less than a third of the time. Referring to this, Mr. Proctor very pertinently asks, 'Can the north-east trades, by blowing for less than one-third of the time, cause the Gulf Stream to run all the time, and without varying its velocity either to their force or prevalence?' Mr. Proctor adds another argument, which, in our opinion, settles the question definitely. After referring to the fact that the trade-wind zone of the northern hemisphere is not constant in position, but travels northwards and southwards with the northerly and southerly motion of the sun in declination, he proceeds: 'If we set the extreme shift of the northern trade zone at 10°, we are certainly not overrating it. Now, taking this zone as extending in spring or autumn from 10° to 25° north latitude, we should have it in winter extending from 5° to 20°—that is to say, the northern 5° of the winter zone and the southern 5° of the summer zone, each zone being 15° wide. Now if any one will mark these zones on the North Atlantic, he will find that while the zone of winter trades would produce a current flowing into the southern half of the Gulf of Mexico, the zone of summer trades would produce a current flowing into the northern half. The former would produce a current flowing as the Gulf Stream actually flows, the latter would produce a current flowing in exactly the opposite direction.' Notwithstanding these objections, which are certainly valid for the particular cases referred to, it is indisputable that winds do play an important part in the production of oceanic currents, and, indeed, may with perfect truth be said to be the most active auxiliaries, if not the principal agents, in effecting those movements of the surface strata of the waters of the ocean to which the term 'horizontal circulation' has been given. Of currents that may be referred as being chiefly due to the long-continued agency of the wind, we have the best examples in the equatorial drifts of the Atlantic and Pacific Oceans, while in the northern part of the Indian Ocean, where the winds blow north-east at one season and south-east at another, the currents change their direction also, thus showing most conclusively that these, at any rate, are primarily and solely due to the prevailing winds. Having thus placed before the student, as clearly as possible consistent with necessary brevity, the theory that oceanic currents are solely due to the action of winds, and having also noticed the principal objections to it, we may add that, in our opinion, winds do certainly assist in producing a general horizontal circulation of the waters of the ocean, and may even be said to be the *primum mobile* of certain surface currents, but that to refer the propulsion of such vast currents as the Gulf Stream, etc., to the direct agency of the winds is certainly inadmissible.

Captain Maury, in his *Physical Geography of the Sea*, asserts ocean currents to be primarily due not to the winds, but to the differences in temperature and salinity. In consequence of the high temperature in tropical regions, the water expands and becomes lighter — or, in other words, expansion causes a decrease of density, and consequently a difference in level. The cold of polar regions, on the contrary, contracts the water, thus increasing its density, and also resulting in a difference of level; but with this distinction, that while the equatorial waters are higher than the normal level, the polar seas are lower. A slope is thus said to be produced, down which the warm waters of the tropics flow slowly towards either pole as surface drift, the equilibrium being restored by an under flow of cold water from the Arctic and Antarctic Seas. To this view it is objected, in the first place, that as tropical seas are subject to active evaporation, the difference in level due to the expansion of the water by heat is counteracted by such evaporation, and the water therefore remains at its normal level. If this be true, the theory that the difference in level between the equatorial and polar seas causes surface currents to flow from the former to the latter cannot be maintained. Besides this, it is asserted by Mr. Croll that, supposing the temperature of the water at the equator to decrease uniformly from the surface downwards, we should have to descend to a depth of 10,000 feet in order to find a stratum of water as cold as the surface strata of the polar seas. Basing his calculations upon this supposition, and for the moment ignoring the action of evaporation in counteracting the effects of expansion, he came to the conclusion that the difference in level between the water at the equator and that at the poles would be about 18 feet, and thus the inclination between the equator and either pole, about 6200 miles distant, would be 18 feet in 6200 miles, or 3 feet in about 1000 miles. But, as M. Dubuat has experimentally proved, the motion of the water is entirely arrested on a slope twice as much as this; and, arguing from this fact, Mr. Croll infers that the inclination produced by the difference of temperature between the equatorial and polar seas is such that it cannot possibly have any effect in producing currents, not even the 'trifling surface drift' asserted by Sir John Herschel to be due to this cause.

Dr. Carpenter's theory is essentially the same as Captain Maury's, and is based upon the fact that differences in temperature cause differences of level and density. Dr. Carpenter, however, attaches much greater importance to polar cold than equatorial heat; the former, he avers, gradually influences the whole mass from the surface to the bottom, while the influence of the latter does not penetrate more than 100 fathoms deep. The density of the surface water of the Arctic and Antarctic Oceans, on being cooled to near the freezing point, is so much augmented that it sinks, thus exposing a new surface to the same cooling process; this in its turn sinks, so that the lowest strata of the water in the polar seas is at or very near the freezing point. But this sinking of the surface water, on cooling, disturbs the equilibrium, and therefore a surface flow of the warmer tropical waters takes place in consequence of the tendency to the equalization of level, the colder polar waters, in the meantime, moving along the sea bottom towards the equator to restore the equilibrium. Thus there are two great primary sets of currents put in operation,—a surface current of warm water from the equator to either pole, and an under current of cold water from either pole to the equator. Now, if this be the case, we would naturally expect that the temperature of the lower strata of water, in all the great ocean basins communicating directly with the polar seas, would be in proportion to the freedom of communication in each case—that is, that if the lowest stratum of water in a basin, communicating freely with either polar basin, be found to be of the same temperature, we may reasonably infer that it is due to an influx along the sea bottom from the polar basin. This has been found to be the case, and even under the equator the lower strata of water preserve an almost glacial coldness. This is still further strikingly proved by the fact that the temperature of the lower strata in enclosed basins corresponds with that of the lowest stratum of the ocean opening into them; and in several instances, notably the Sulu and Banda Seas, the water at the bottom has been found to be of the same temperature as that immediately overlying the enclosing ridge; and thus at the same depths, inside and outside the ridge, there may be a difference in temperature of many degrees. Dr. Carpenter applies his principles to certain particular cases, such as the Mediterranean and Baltic Seas, and concludes that, on the same principles, a vertical circulation must be maintained 'between the polar and equatorial waters by the difference of their temperature, the level of polar water being reduced and its density increased by the surface *cold* to which it is subjected, whilst a downward motion is also imparted to each stratum successively exposed to it, and the level of equatorial water being raised and its density diminished by the surface *heat* to which it is exposed. The first of these agencies is by far the more effective, since it extends to the *whole depth* of water, whilst the second only affects in any considerable degree the *superficial stratum*. Thus a movement will be imparted to the upper stratum of oceanic water from the equator to the poles, whilst a movement will be imparted to the deeper stratum from the poles to the equator.' As proofs of a general vertical circulation of the waters of the ocean, Dr. Carpenter points out the general *northerly* movement of the upper stratum of the water, and to the general prevalence of a temperature closely approaching the freezing point of fresh water over the bottom of the great oceanic basins communicating with either of the polar areas. He further illustrated his theory by the following experiment: —Having poured some water into a long trough with glass sides, he placed a piece of ice in one corner. On the other end a piece of metal was placed in contact with the water, and heated by



A B C D is a long trough with glass sides.
a b is a piece of metal resting on the water in trough at *b*, heated by a lamp at *a*.
c contains a lump of ice.
Near D a little *blue* colouring liquid is put into the water, and a little *red* colour near B; and it is thus seen that there is a continuous circulation in the direction of the arrows.
b of course is intended to represent equatorial region, and *c* polar region.

means of a lamp. Upon introducing a little blue colouring liquid into the water near the ice, and a little red colour near the heated metal, a continuous circulation from the cold to the warm end of the trough was manifest.

94. **Phenomena of Arctic and Antarctic Regions —Floes, Pack Ice, Icebergs, etc.**—This portion of our subject will be more appropriately introduced after the consideration of the nature and formation of aqueous vapour, rain, ice, and snow; indeed, without some acquaintance with these preliminary points, the student can scarcely be expected to form clear and definite notions as to the various phenomena observable in these regions. We propose, therefore, to reserve the consideration of these interesting phenomena until we shall have placed before the student as clearly as possible, and as fully as our limited space will permit, the preliminary observations absolutely necessary to an intelligent comprehension of the physiography of the polar regions. Reserving these points, then, for the next chapter, we shall conclude the present with a brief explanation of the action of the sea upon the earth's crust, and its influence in the distribution of climate.

95. **Action of the Sea upon the Earth's Crust.**—We have already seen how the surface of the land is gradually worn away by the denuding action of atmospheric agencies, supplemented by aqueous action; how that the particles loosened from the rocks or soil by wind and rain are swept away by rivers into the sea, over the bottom of which they are deposited in more or less regular layers or strata. But besides the sediment brought down by rivers, the various movements of the sea itself are important geological agencies, productive of

great changes in the earth's crust. Waves, tides, and currents all act on the earth's crust, either directly or indirectly: waves directly, by wearing away the shore against which they continually break, grinding down the detached masses, ultimately reducing them to minute fragments or gravel, and then into sand; tide waves and currents, on the other hand, take up the finer particles, and transport them, it may be, for hundreds of miles before they are finally deposited on the sea bottom. The extent of the action of waves upon a coast depends, first, on their force and magnitude, and, secondly, upon the composition and arrangement of the rocks on that coast,—the softer parts, of course, being worn away first, leaving the harder portions still intact. It is in this way that all bays and promontories have been formed. To a casual observer, the sight of the waves rushing on the shore, and retreating again with a deafening noise, would convey but a faint idea of their degrading power; but were he to observe accurately the position of some fixed object, and the exact distance of the highest water-mark, and if, on visiting the spot again, some years after, he made the same observations, a comparison of the respective distances would show the extent of wave action at that point. If the observer had thus examined a coast consisting of the softer and looser materials, as along some part of the eastern coast of England, the waste would be found to be very considerable, and the sea would be found to advance several feet annually. Other parts of the coast, again, formed of the harder and more compact rocks, are not so easily disintegrated, and even very long-continued wave action is scarcely perceptible, although the force with which waves strike, especially when directly against the shore, is enormous. Of course, all bodies lose nearly a third of their weight in water; but granting this, their abrading and transporting power is almost incredible, were not the facts perfectly reliable. Blocks weighing more than 800 tons have been known to be displaced, breaches have been made in sea walls, lighthouses swept away, and even breakwaters have been broken down. The pressure of the Atlantic breakers on the west coast of Scotland has been estimated by Mr. Stevenson at 611 lbs. per square foot in summer, and 2086 lbs. per square foot in winter. The Bell Rock Lighthouse, 112 feet high, is sometimes buried in spray from ground swells when the storm has abated. The force necessary in this case was estimated to be not less than 6000 lbs. or nearly 3 tons per square foot. In the English Channel, the spray has been observed to be driven right over the lantern of the Eddystone Lighthouse, at a height of 140 feet; and during the storm that broke down the breakwater at Wick, the spray was supposed to rise as high as 150 feet. The configuration of any coast, therefore, is not, strictly speaking, stationary or fixed, but is subject to change from the action of the waves which dash against it continually—slow, indeed, in some places, but in others comparatively rapid. Waves, then, may be said to affect the shore line; tides and currents, on the other hand, transport the debris produced by waves, rivers, etc., it may be to great distances. But ultimately all the particles, even the finest sand, will be deposited on the floor of the ocean, gradually filling up any submarine cavities that may exist, and thus, in lapse of ages, producing the characteristic uniformity of the bed of the ocean, as compared with the land. Another evidence of the 'power of winds and currents of prevailing direction on the grandest scale, and one which argues the long persistence of these currents, is offered by the chart of the whole world; for there it is plainly seen that all of the larger groups of continental islands, or those which we have recognised as fragments torn from the continents, such as the British Isles, the West and East Indian Archipelagos, lie directly across the path of the strongest prevailing streams of wind and water, while those coasts away from which prevailing winds blow are uniformly rounded and complete, without a single continental island.'

96. **Influence of the Sea in the Distribution of Climate.**—Water, as we have already observed, has a greater capacity for heat, or, in other words, has a higher specific heat than any known substance. By this we mean that more heat is required to raise the temperature of a given quantity of water to a certain degree than it does to raise a similar quantity of any other substance to the same degree; and conversely, more heat is given off when the temperature of a given quantity of water is lowered a certain number of degrees than is liberated by the reduction of the temperature of any other substance to the same degree. Tyndall (*Heat as a Mode of Motion*) gives the determinations of the specific heat of equal weights of the most important known substances, and taking that of water as 1, that of mercury, for instance, is given as 0·0333,—that is, given equal amounts of water and mercury, to raise the temperature of both 1° would require 30 times as much heat to raise the water as it would the mercury; and conversely, the reduction of the tempe-

rature of equal amounts of water and mercury 1° is followed by the liberation by the water of 30 times more heat than that given off by the mercury. So that different substances are not equally heated by equal degrees of heat. For instance, four times the heat required to raise the temperature of one pound of chalk, or nine times that required to raise one pound of iron, 1°, would be necessary to raise one pound of water 1°. The surface strata of the land is of course composed of very different materials in different places; and these various substances, again, all differ in their capacity for absorbing and radiating the heat received from the sun. But we may say that, on an average, the respective capacities of land and water are as 0·25 is to 1,—that is, four times as much heat is required to raise a certain area of water to the same temperature as a similar area of land, supposing, of course, both to have the same initial temperature. This greater capacity of water for heat is due to the fact that the heat received is not transmitted from particle to particle as in solids, but is entirely effected by *convection*, or by the actual displacement of the heated particles by others not yet heated to the same degree. The heat falling on the land, on the contrary, is communicated to the underlying particles by *conduction*, and not by any actual transference of the heated particles, which, of course, in this case is impossible, as the solid particles of earth are motionless. This process of conducting the surface heat downwards being necessarily very slow, it follows that the heat received during the day accumulates on the surface layer, and, in some cases, as where the surface is covered with sand, the accumulated surface heat is such that surface temperatures of 120° F. or even 150° F. have been observed. But the heat thus quickly gained during the day, affecting the surface superficially only, is as quickly dissipated in the following night; and the longer the sun is above the horizon, the more heat is received, and the shorter the night, the less heat is lost. Hence in summer more heat is gained in the long day than is lost in the short night, and *vice versa*, in winter, more heat is lost during the long nights than is gained in the short days. There is therefore a wide difference between the surface temperature of the land during the day and at night, in summer and in winter. On the other hand, the heat that falls on the sea is not so readily absorbed by the surface particles as is the case on land; but then the particles of water are not, like those of the land, motionless, but are, as soon as heated, displaced by other cooler particles, which are in turn heated and similarly displaced; and as we have said the particles of earth have no motion like those of the water, the result is that on land the *same* particles are constantly exposed to the heat rays, and as the heat received by these surface particles is conducted downwards very slowly, it accumulates on the surface. But the surface particles of water, as soon as heated, are transferred and replaced by other colder particles, and thus the heat received is not accumulated on the surface as on land, but is distributed through the water to a considerable depth. The superficial heat of the land, therefore, is much more rapidly dissipated than that of the sea. The sea, then, is, as it were, nature's storehouse of heat, amply providing for the exigencies of the land. Its surface heat, too, is thoroughly diffused through its mass to considerable depths by means of waves, tides, and currents; the initial cause of the most important of the latter being, indeed, the constant tendency to equilibrium, as regards temperature, between the warmer equatorial waters and the colder polar seas. From these considerations, therefore, we conclude that as the water requires much more heat than the land to raise it to the same temperature, in summer the land is warmer than the contiguous ocean; but, on the contrary, in winter, the land is colder than the adjoining sea. In summer, then, the winds blowing over the heated land from the cooler ocean will cool it by abstracting the excess of surface heat, while in winter the same winds blowing from the warmer sea to the colder land will warm it. Hence maritime countries are not subject to extremes of heat and cold, the heat of summer and the cold of winter being modified by the influence of the adjoining ocean communicated to the land by means of winds and air currents. Such countries are said to have an *insular climate.* On the other hand, places at a distance from the sea, or only partially subject to its influence, have extremely hot summers and very cold winters. Such places are said to have a *continental climate.* This difference in equability of climate consequent on proximity to the sea is strikingly illustrated in Europe, the mean annual range or difference between the summer and winter temperatures constantly increasing as we proceed eastwards. Thus at Warsaw, although in the same latitude as Dublin, it is warmer in summer, but colder in winter. Again, over the ocean at the equator, the difference in temperature of day and night scarcely ever exceeds 4°, while upon the land it amounts to 10°. Paris, for instance, has a mean diurnal range of 25°

to 30°, while over the sea in the same latitude the difference is only 4° or 5°. Again, although Edinburgh and Moscow are nearly equidistant from the equator, yet the average summer temperature of the former is 57°, and the latter 64°, the average winter temperature being 38° and 15° respectively; thus showing a mean annual range at Edinburgh of 19° (57° – 38°), and at Moscow of 49° (64° – 15°). Further, as land preponderates in the northern hemisphere, the tendency will be towards a continental climate; and as the reverse is the case in the southern hemisphere, the land there will enjoy a more or less insular climate,—that is, in the northern hemisphere the range increases much more rapidly in proportion to the distance from the sea than in corresponding latitudes in the southern hemisphere. The northern hemisphere, therefore, has a much higher mean temperature than the southern, and the variations are much more striking. Of course, there are other causes which modify the climate of a country besides its proximity to or distance from the sea. Among these are the prevailing wind currents, elevation, physical character of the country, etc. These we shall notice more particularly when we come to treat of the *general conditions of climate.* Geographers, however, are not quite agreed as to the climatical action of the winds, some holding that the general atmospheric circulation is not a cause 'by which the superabundant tropical heat is carried to and distributed over the more temperate regions of the earth's surface,' but that the tropical heat is transferred by the Gulf Stream and other similar currents. Others, again, while not denying the great climatical influence of thermal currents, affirm that this transference of the excess of heat in the tropics is chiefly performed by air currents. As regards the former, the mean of various estimates shows that the heat conveyed by the Gulf Stream into the Atlantic is equal to one-fourth the total amount received from the sun by the whole area of this ocean,—that is, supposing all the heat to be absorbed, which, of course, is not the case, the greater portion being dissipated in the process of evaporation. The stoppage of the Gulf Stream alone, then, would deprive the Atlantic of one-fourth of its heat, and would therefore materially alter the climatical influence of that ocean north of the equator. But, besides the Gulf Stream, there are other vast currents constantly transferring the warmer tropical waters to the northern temperate and arctic regions, and the amount of heat thus abstracted from the southern hemisphere being added to that received directly from the sun by the northern hemisphere, results in the much higher mean temperature of the latter. 'These considerations point to the enormous climatical influence of thermal oceanic currents. Owing to the earth's spherical form, a superabundance of heat is received at the equator, whilst in high latitudes far too little is received to make the earth habitable for mankind. Oceanic currents, as we have seen, modify this state of things by transferring heat from the torrid zone to the temperate and frigid zones. Aerial currents have another function, and upon the twofold arrangement depends the thermal condition of the globe. *Stop the oceanic currents, and the world is in high regions uninhabitable.*'

CHAPTER XII.

ON THE ATMOSPHERE AND ATMOSPHERIC PHENOMENA.

97. **Composition of Air.**—Ancient philosophers classed air as one of the four elements, the other three being water, earth, and fire. Modern investigations and discoveries, however, have long since overthrown this simple resolution of all matter into four so-called elements. Air, water, and earth are no longer considered as simple homogeneous substances, as all three have been practically shown to be compounds of two or more elementary substances; while the fourth so-called element, fire, is simply a state or condition caused during the process of combustion, and therefore not a substance at all. At present, we shall confine our attention to the first, air. Perfectly pure air may be said to consist of oxygen and nitrogen in the proportion of 21 volumes of the former and 79 volumes of the latter in every 100 volumes of air, or *by weight* of 23 parts of oxygen and 77 parts of nitrogen. But in addition to these two gases, which constitute the bulk of the atmosphere, air is nearly always found to contain a minute percentage of other gases (principally carbonic acid and ammonia gas) and aqueous vapour. Air, therefore, is not a simple homogeneous element in the sense in which the term is now used; nor, on the other hand, how-

ever paradoxical the statement may appear, is it, chemically considered, a compound. Chemical compounds are formed by the chemical union of two or more elements, and are such that in all chemical combinations there is a change in bulk, temperature, and properties. If, therefore, air is a compound, the effect of bringing together its constituent elements in the relative proportions in which they are found would necessarily be similar. But if oxygen and nitrogen in the proportion of 21 to 79 by volume, or 23 to 77 by weight, be introduced together into a closed vessel, no such changes in bulk, temperature, or properties take place as always accompany chemical combination, thus showing clearly that the two gases are simply mixed together, and not chemically combined. Further, as we explained in the articles on chemical action, chemical elements will only combine in certain definite and unvarying proportions,—that is, the relative quantity of each element must be that of its combining weight or of a multiple of that weight. In 100 parts of air, the proportion by weight of oxygen is 23, and nitrogen 77, while the combining weights of these two gases are respectively 14 and 16, a difference altogether incompatible with the notion of a chemical union of these gases. The most convincing proof that air is not a chemical compound is that given by Roscoe, derived from an experiment upon the solubility of air in water, and which he thus describes:—'When air is shaken up with a small quantity of water, some of the air is dissolved by the water. This dissolved air is easily expelled again from the water by boiling, and on analysis this expelled air is found to consist of oxygen and nitrogen in the relative proportion of 1 and 1·87. Had the air been a chemical compound, it would be impossible to decompose it by simply shaking up with water: the compound would then have dissolved as a whole; and, on examination of the air expelled by boiling, it would have been found to consist of oxygen and nitrogen in the same proportion as in the original air, viz. as 1 to 4. This experiment shows, therefore, that the air is only a mixture, a larger proportion of oxygen being dissolved than corresponds to that contained in the atmosphere, owing to this gas being more soluble in water than nitrogen.' The composition of the air by volume is best determined by means of the *eudiometer*, and the mean of many analyses made in all parts of the globe confirms the important fact of the remarkable uniformity in the composition of the air, the proportion of oxygen and nitrogen, 21 and 79, being found to be almost invariable everywhere, whether the air be taken at sea level, or at elevations of 10,000, 20,000, and in one case of 23,000 feet, or from the equatorial or the arctic regions, at the surface or at the bottom of the deepest mines. But, as we have said, the air contains minute quantities of other gases, such as carbonic acid, ammonia gas, and aqueous vapour. Now, as the density of the several gases present in the air differs, we would naturally expect that the heavier and denser gases would on that account be confined to the lower strata of the atmosphere, while the lightest would occupy the higher strata. Instead of this, we find that carbonic acid, the heaviest of all, is present in air at great elevations, and the lightest, viz. nitrogen and aqueous vapour, have been found in air at the bottom of mines several hundred feet deep, thus proving that the various gases of which the air consists are diffused throughout the whole atmosphere. The oxygen and nitrogen only, however, may be said to be *equally* diffused, the relative quantities of these two gases remaining the same under nearly all conditions. This, however, is not the case with the other minor but still most important constituents of air. For instance, the quantity of carbonic acid varies considerably, being more abundant at night than during the day, in summer than in winter. The percentage of carbonic acid as compared with oxygen and nitrogen is very small, 100 parts of air containing only 0·04 of carbonic acid—that is, 4 volumes in every 10,000 volumes; yet the total amount, 3000 billion kilometres, is enormous, and amply sufficient to provide the carbon absolutely necessary for plants in the process of vegetation, the carbon being taken in by the plants, and the oxygen liberated. Under exceptional circumstances, the proportion of carbonic acid is as low as 2 volumes in 10,000 volumes of air, but in badly-ventilated workshops, halls, etc., this proportion rises to more than 10 in 10,000. The quantity of aqueous vapour in the air also is not constant, but varies with locality, season, direction of the winds, but principally with the temperature of the air; for the higher the temperature is, the more aqueous vapour will be held in solution, so that the proportion of aqueous vapour in the air depends upon the temperature; and if this be lowered, the vapour which it is now unable to retain will be condensed and precipitated as rain or snow. When air at a given temperature holds the maximum quantity of aqueous vapour, it is said to be saturated, and generally speaking the amount of aqueous vapour is from one-half to three-fourths the maximum quantity. Ammonia, so important to vegetation, is also found in the air, but in very small quantities, only about 1 part in 1,000,000. Other substances are also found in the air of particular localities, and it is upon these accidental and local ingredients that the healthiness or unhealthiness of a place depends. Jungles and low marshy plains, from which noxious exhalations constantly rise, are notoriously unhealthy, while dry, elevated regions, even under the equator, are salubrious. Perfectly fresh and pure air always contains *ozone*, the formation and nature of which, however, cannot as yet be said to have been definitely determined. Its presence is indicated by a peculiar smell, as when an electrical machine is in operation, or when bodies are struck by lightning; and to its greater abundance on the sea-coast than in inland districts may be attributed the greater salubrity of the former. Ozone may be artificially produced by passing a series of electrical currents through a vessel containing pure oxygen gas: part of the oxygen will be condensed into ozone, which thus seems to be simply condensed oxygen; but it may be produced in many other ways. In nature it is most probably produced by electrical disturbances in the air.

98. **Height of the Air.**—Having thus briefly sketched the composition of the aerial envelope which surrounds the globe, let us revert to the considerations from which its height above the earth's surface has been determined. That it is not extended into space is evident; for if so, the motions of the earth and all the other planets through such a medium would be retarded, and in time stopped altogether. That light cometary bodies, such as Eucke's comet, are sensibly retarded in their progress, is now proved beyond a doubt, and this retardation must be due to the resistance of some

medium which fills space. That such a medium is not air, however, is evident; for if it were, the retardation would be much greater than it is. Space, then, is not a *vacuum*, as formerly supposed, but is filled with a highly-attenuated medium called *ether*. It is clear, therefore, that the atmosphere which surrounds the globe is not prolonged indefinitely into space, but is, as it were, attached to the earth, revolving with it in its daily rotation, and carried along with it in its revolution round the sun. Having thus concluded that the atmosphere is limited, it remains to us to consider how we may determine approximately this limit, which has never been definitely ascertained, and probably never will be. Were the air of equal density throughout, its height could be easily and accurately ascertained; for if, as we shall show in the next article, the weight of the air balances a column of water 32 feet high, and water be 842 times heavier than air, then the extreme limit of the atmosphere will be at a height of 842 × 32 feet, or 26,880 feet, or a little over 5 miles, so that some of the mountain peaks of the Himalayas and elsewhere would be above the atmosphere. But we know very well that the air is not of the same density throughout, that the higher we go the lighter the air is, or, in other words, the less the superincumbent pressure, so that the air thins out, as it were, from the surface upwards. This increased expansion and rarefaction consequent on increased elevation apparently suggests the idea that, owing to its expansive force, its molecules would separate indefinitely in all directions into space. But the greater the expansion, the less the expansive force, and the higher the elevation, the lower the temperature; and these two factors, diminished expansion and a low temperature, aided by the force of the gravitation, check further expansion into space, so that the atmosphere is undoubtedly limited, extending to a certain definite distance from the surface. From observations on twilight, which is due to the refraction of the sun's rays after it has disappeared below the horizon, it is calculated that the height of the air is between 30 and 40 miles; but this estimate is based on the generally-received notion that the twilight ceases when the sun is 18° below the horizon. A sensible illumination, however, has been observed when the sun must have been much further below the horizon than 18°, so much so, indeed, that we may reasonably conclude that the power to reflect light, in a slight degree, it is true, does not cease at a less height than 200 miles. Many observations on meteors, also, prove conclusively that there must be air dense enough to make them luminous at a height of 200 miles, and M. Liais, from certain observations at Rio de Janeiro, fixes the extreme limit at 212 miles. From the very nature of the investigation, however, we can scarcely hope to arrive at any definite conclusion as to the height of the atmosphere, at least in the present state of scientific knowledge.

99. Atmospheric Pressure, and Use of Barometer.—That air is a material although invisible substance, is proved by the fact that, like solid and liquid substances, it has weight, or, in other words, is subject to the force of gravitation. The absolute weight of air and other gases has been thus determined. Let the air in a glass globe of known dimensions be exhausted by means of an air-pump, and the globe be then carefully weighed. After readmitting the air, let the globe be again carefully weighed. On comparing the results, the weight of the globe when exhausted of air will be seen to be less than when full of air; the difference in weight in the two cases, then, is evidently the weight of the contained volume of air. By this means it has been found that 100 cubic inches of dry air under the ordinary atmospheric pressure weighed 31 grains. The general pressure of the air may be illustrated in many ways. For instance, if a piece of bladder be stretched across the mouth of a vessel from which the air has been exhausted, the bladder is seen to be bent downwards, and is finally burst by the pressure of the air above it, there being no air inside to counteract or equalize the pressure. The exact amount of pressure, or, in other words, the weight of the air, is determined by means of the *barometer*, which is simply a glass tube about a yard in length, and a bore of about a quarter of an inch in diameter. This tube is filled with mercury, as is also a small trough or cistern, into which it is inverted, open end downwards, the mercury in the tube being prevented from running out by placing the thumb over the orifice. Upon removing the thumb, the column of mercury will be seen to sink, finally resting at a point about thirty inches above the surface of the mercury in the trough, if the experiment be made at sea level; thus showing that at sea level the pressure of the air on the surface of the mercury in the trough exactly balances a column of mercury 30 inches high. But if the experiment be made at any considerable elevation, for instance at the Hospice of St. Bernard (8200 feet), the column of mercury will fall to 22 inches, thus showing a diminution of pressure. Humboldt found that it fell to 14⅔ inches. at an elevation of 19,332 feet above sea level. The diminution in pressure, then, is shown by the fall of the barometric column, and the fall of the barometric column therefore indicates the degree of elevation. The absolute amount of atmospheric pressure may thus be estimated; for if the pressure of a column of air balances a column of mercury 30 inches high, and if the area in each case be supposed to be a square inch, the weight of the former will be equal to that of the latter. Now a cubic inch of mercury weighs ·49 lb., and 30 cubic inches will therefore weigh 14·7 lbs. The atmosphere therefore presses with a weight of 15 lbs. on every square inch, or 2216 lbs. or nearly a ton on every square foot, which is exactly equal to what would be the case were the earth covered with a layer of mercury 30 inches high, or a layer of water 34 feet high. A pressure of 15 lbs. on a square inch is therefore called a pressure of *one atmosphere;* a pressure of 30 lbs. on a square inch, *two atmospheres*, etc. The body of an average adult presents a surface of about 15 square feet. The pressure therefore is 33,240 lbs., or nearly 15 tons. This enormous pressure is borne without the least inconvenience; in fact, it is absolutely necessary to the preservation of life, because it is equal on every side, inside and outside; and this equalization of pressure is so nicely adjusted that we are, as it were, in a state of equilibrium as regards atmospheric pressure, which is therefore not perceived or felt. That the atmospheric pressure diminishes with altitude is shown also by the diminished temperature at which water boils. Thus, under the normal atmospheric pressure at sea level, water boils at 212° F.; but, for instance, at a height of 13,000 feet in the Andes, water boils at 190° F., the general diminution being 1° F. for every 600 feet of ascent. We can thus determine *approximately* the elevation of any place by means of the thermometer as well as the barometer; but in both cases the results vary in different places and under different conditions, so that, in order to determine the exact height, various corrections and reductions must be made. Thus the correction for height in England is ·001 of an inch for every 400 feet of ascent; at the equator, ·003 must be subtracted from the observed height, while at the poles ·003 must be added. Again, the absolute pressure of the air is affected by its temperature, diminishing with a high and increasing with a low temperature; the number of degrees, then, corresponding to the elevation must be added to the observed temperature.

100. **Distribution of Temperature, Horizontal and Vertical.**—In the chapter on the 'Temperature of the Interior of the Earth,' we remarked that although many astronomical and other considerations warrant our refutation of the 'fluid theory' as being a physical impossibility, yet that this is not necessarily inconsistent with the *fact* of a high interior temperature, of which the existence of volcanoes and thermal springs are conclusive proofs. But, owing to the weak conductivity of the rocky crust, this intense interior heat of the earth cannot be said to affect the surface temperature of the globe in any sensible degree. From many observations on the increase of temperature downwards, and experiments as to the average conducting powers of the materials of which the crust is composed, it has been estimated that the influence of the interior heat of the globe upon its surface temperature does not exceed $\frac{1}{17}$ of a degree Fahrenheit, an amount so minute that for all practi-

cal purposes it may be ignored. The temperature of the surface of the earth, or, as it is termed, the *superficial temperature*, may therefore be said to depend upon the amount of heat received from external or extra-terrestrial sources, such as the sun, moon, etc., but chiefly from the sun, that received from all other sources whatever being so inconsiderable as to have no sensible effect on the surface of the globe. The terms 'horizontal' and 'vertical' distribution of temperature, therefore, simply mean the manner in which solar heat is received and distributed over the earth's surface,—horizontally, from the equator to either pole; vertically, from sea level to the highest elevations. In the first place, then, let us consider the horizontal distribution of temperature, or, in other words, the effect of latitude on temperature. This is the most important element in the distribution of temperature, although greatly modified by the irregular distribution of sea and land, elevation, aspect, and other minor causes, and is roughly shown by the division of the globe by the tropics of Cancer and Capricorn, and the arctic and antarctic circles, into five great zones or belts, viz. the torrid, occupying a space 23½° north and south of the equator; the frigid zones, 23½° from either pole; the temperate zones, the intermediate space. The torrid is characterised by extreme heat, the frigid by extreme cold, the temperate zones having a medium temperature. Now the amount of heat that falls upon the surface of the earth depends chiefly on the angle of incidence and time of exposure; and the greater the obliqueness of the direction of the sun's rays, the greater the number of rays lost or radiated. Thus when the sun is in the zenith, the rays fall perpendicularly, but when near the horizon, almost horizontally. In the former case it is estimated that out of 10,000 rays falling on the air, 8123 reach the surface, while in the latter case only 5 out of 10,000. This, therefore, is the principal reason why the sun's heat affects the tropical regions more powerfully than the temperate, and the temperate more than the polar. But as the earth is inclined to its orbit, the equator does not indicate the path of the point of *direct heat* over the earth's surface. This is shown by the ecliptic, which cuts the equator at an angle of 22½°. Strictly speaking, therefore, it is not correct to say that the heat diminishes as we move north or south from the equator; for when the sun is north, the heat decreases as we approach the equator, and *vice versa.* This is also shown by the fact that the snow-line is at its highest limit not *at* the equator, but at some distance north or south. As we have said before, land and water differ greatly in their respective capacities for heat; consequently we find that the northern or land hemisphere has extreme summers and winters, while the southern or water hemisphere has a more equable climate. Other conditions also affect the horizontal distribution of temperature, a clear notion of which can only be obtained by a careful comparison of charts on which lines connecting places of the same mean temperature are drawn. By the *mean temperature* of a place, we mean the average of a number of temperatures recorded at certain intervals. Thus the mean temperature of any day is the average of the observed temperature during each of the 24 hours, and the average of 365 mean daily temperatures would show the mean annual temperature. Now if the mean annual temperature of a number of stations in all parts of the globe be determined, and all those places having the same mean annual temperature be connected by lines, such lines would show exactly the horizontal distribution of heat. Lines connecting places of the same mean annual temperature are called *isothermal lines*, or lines of equal heat. If the surface of the earth were uniform—that is, either all land *at the same level*, or entirely covered with water—these lines would be parallel to the equator, and would show a regular decrease from the equator to the poles. But if the student turns to any such charts, he will find that the isothermal lines, instead of being parallel to the equator, like the lines of latitude, are wavy and irregular, bending sometimes almost due north and south, thus showing that the effects of latitude are modified by special or local conditions in any district. But places having the same *mean* annual temperatures may yet have very different climates; for example, London and Vienna, although very nearly of the same mean annual temperature, the mean winter temperature of the latter is 29°, while that of London is 37°, a difference of 8°. Again, the mean summer temperature of Vienna is 70°, of London 64°, a difference of 6°. In order, therefore, to form a just comparison between the climate of any two places, their mean summer and winter temperatures must be considered as well as their mean annual temperature. Lines connecting places having the same mean summer temperature are called *isotheral lines*, those showing the mean winter temperature, *isocheimal lines*.[1] By the *range of temperature* is meant the difference

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[1] In studying this portion of the subject, the student is strongly recommended to consult Keith Johnston's *Book of Physical Geography* (Stewart & Co.).

between the mean temperature of the warmest and coldest months. Immediately around the equator this is inconsiderable; as we proceed northwards it increases, being in England 27°, and at Yakutsk, the greatest yet known, 106°.

Countries having a range of 30° or under are said to have an *insular* climate; those ranging from 30° to 60°, a *continental* climate; if the variation exceeds 60°, the climate is said to be *excessive* or *extreme*. The student must remember, however, that in all charts showing the isothermal lines, the isotherm only indicates the temperature at sea level, or that at which all places through which it passes would be if reduced to sea level; this is effected by adding 1° for every 300 feet of elevation. Were lines drawn to indicate the actual mean temperature of a district at all elevations, we would have a series of rings gradually closing in towards the most elevated parts, and ranging, if at the tropics, from 80° to the freezing point. Such a series of rings, showing the decrease of temperature with elevation, would illustrate the *vertical distribution of temperature;* and thus a high mountain range in the tropics exhibits all the varieties of climate, from the torrid at the foot of the range, to the frozen at and above the snow-line. The mutual reaction of the vertical and horizontal distribution of temperature is clearly shown by the varying height of the limit of perpetual congelation, from sea level at the poles to about 16,000 feet at the equator. But, as in the horizontal distribution of heat at sea level, the decrease is not regular, varying under local conditions; thus the snow-line on the northern side of the Himalayas is 4000 feet higher than on its southern side. The decrease north and south will be best seen from the following table of the snow-line in corresponding latitudes in the northern and southern hemispheres (see p. 202).

101. **Use of the Thermometer.**—As Professor Young remarks, the sensation of heat or cold is relative, like that of salt and sweet, or any other pair of contrasting impressions,—that is, the impressions conveyed to different persons by the same actual degree of temperature depends entirely upon the conditions of temperature which they previously experienced. For instance, a traveller, ascending a high mountain from the heated plains below, complains of the cold at a place where another, descending from the regions of perpetual snow, complains of the heat. The sensation of heat and cold, therefore, being purely relative, and depending entirely upon previous conditions, cannot be taken as a standard to measure the *actual* temperature. This can only be ascertained, with any degree of accuracy, by observations on the physical action of heat on inorganic bodies. Heat, as is well known, affects bodies in various ways, the most simple, however, being that of expansion under a high, and contraction under a low temperature. Solids, liquids, and gases expand on the application of heat; but the expansion of solids is so minute as to be practically useless for this purpose, while that of gases, on the other hand, is by far too great to be accurately and easily observed. Liquids under the effects of heat expand more than solids, but much less than gases, and are therefore more suitable for the purpose of ascertaining the actual amount of heat by the actual degree of expansion. Of liquids, mercury and alcohol are only used, mercurial thermometers being most accurate in observing high temperatures, as the mercury

TABLE SHOWING THE SNOW-LINE IN THE NORTHERN AND SOUTHERN HEMISPHERES.

Lat.	NORTHERN HEMISPHERE.		SOUTHERN HEMISPHERE.	
Deg.		Feet.*		Feet.
80	Spitzbergen, ...	2,500	...	...
65	Iceland, ...	3,100	...	...
56	Kamtschatka, ...	5,200	South Georgia, ...	0
53	Aleutian Islands (Oonalaska), .	3,510	Straits of Magellan, . . .	3,710
46	Alps, ...	8,500	New Zealand, ...	7,800 6,900
43	Pyrenees, ...	9,000	Chilian Andes, ...	6,000
27	Himalayas, ...	19,560 15,500	Bolivian Andes, . . .	13,800
16	Abyssinian Mountains, . . .	14,000	Do., . . .	17,700
0	...	...	Quito, ...	15,800

boils only at very high temperature. Alcoholic thermometers, on the other hand, are used when very low temperatures have to be accurately determined, for alcohol does not solidify at the lowest temperature yet produced naturally or artificially. Mercury, on the contrary, solidifies at $-40°$ F. Both mercurial and alcoholic thermometers consist of a small glass tube with a bulb at one end, the other end, after the necessary operations, being hermetically sealed. In the graduation of thermometers of either kind, two points are first fixed, viz. the boiling and freezing points. In the centigrade thermometer the space between these two points is divided into 100 equal parts, called degrees; in that of Reaumur, into 80 equal parts; but in that of Fahrenheit, invented by him in 1714, and still much used in England and elsewhere, the freezing point stands at 32°, and the boiling point at 212°. The conversion of degrees of one scale into corresponding degrees of another may be made by means of the following formulæ, where F stands for number of degrees Fahrenheit; C, for degrees centigrade; and R, for degrees Reaumur:—

(1.) F into C, thus $\frac{5}{9}(F - 32) = C$.
(2.) C into F, thus $\frac{9}{5}(C + 32) = F$.
(3.) R into F, thus $\frac{9}{4}(R + 32) = F$.
(4.) F into R, thus $\frac{4}{9}(F - 32) = R$.

102. **Evaporation and Condensation.** — The quantity of aqueous vapour in the air varies considerably at different times and in different places. This variation is chiefly due to differences of temperature; for the higher the temperature of the air, the greater the quantity of aqueous vapour it can contain, and *vice versa*. By means of the apparatus used for ascertaining the amount of

carbonic acid in the air, the actual quantity of aqueous vapour present at any time can be also easily determined. It has been thus found that air at 32° F. can hold a quantity of vapour equivalent to a 160th part of its weight; at 80° F., an amount equal to the 30th part; and at 140° F., an amount equal to the 10th part,—of course, in an invisible state. Air at a certain temperature cannot hold more than a certain quantity of vapour; thus air at 80° F. cannot hold *more* than its 30th part by weight of vapour. When the maximum quantity is present, the air is said to be *saturated.* Generally the air contains from about 50 to 70 per cent. of the maximum quantity. If less than 50, it is said to be very dry; and if more than 70 per cent., to be very moist. If, when the maximum quantity, or nearly so, is present, the temperature be lowered, *condensation* takes place, for the air is then unable to hold so much vapour in solution; the quantity in excess is therefore condensed and precipitated in a visible form, as mist, fog, or cloud. As we have just said, the quantity of aqueous vapour varies considerably, and although an enormous quantity is being constantly condensed, forming clouds or precipitated on the surface as rain, the air is scarcely anywhere absolutely dry, being always supplied with moisture by evaporation from the moist surface of the land as well as the sea. Evaporation being chiefly due to the action of the sun's heat, it is most active when the sun's action is most powerful; but it does not entirely cease at any time, though temporarily checked by aqueous pressure, even when the temperature of the air is at or below the freezing point. Vapour is thus given off from water at all temperatures, and, in a slight degree, even from ice and snow.

Evaporation, of course, is most active in tropical regions, where the sun's action is most powerful; and such is the enormous amount evaporated from the sea in this zone, that it is estimated a reduction in level of 8 or 10 feet a year would be the result were there no compensating inflow. Again, were the inflowing current through the Straits of Bab-el-Mandeb to be stopped, the surface of the Red Sea would sink annually at least 20 feet. Although the process of evaporation depends chiefly upon the temperature at the time, it is yet greatly modified by the motion and dryness of the air. For instance, Dr. Dalton found that the quantity evaporated from an area of water of 28·29 square inches, at a temperature of 45° F., during a calm, was 1·36 grains; during a breeze, 1·75 grains; with a high wind, 2·13 grains. And as illustrating the effect of temperature, we may add that from the same area, at 75° F., the amounts were respectively—calm, 3·65 grains; breeze, 4·68 grains; high wind, 5·72 grains. The increase in amount consequent upon the motion of the air is due to the removal of the vapour as it rises into the air, for it is well known that a comparatively very small aqueous pressure upon the surface of the water checks evaporation. But this is strange; for a much greater change in atmospheric pressure does not retard the process in the least, or, if it does, the effect is scarcely perceptible.

During evaporation a considerable amount of heat is always absorbed; and the more rapid the process, the greater the heat thus absorbed, which, however, is not appreciable by the senses, and does not affect the thermometer. It is therefore called *latent* heat, and is given out again on the condensation of the vapour. That heat is thus absorbed during evaporation is proved beyond the shadow of a doubt, by the fact that water may be actually frozen by means of rapid evaporation. Thus the cooling effect of a breeze on the body is not due to its lower temperature, as it may be actually warm, but arises from its facilitating the rapid evaporation of moisture from the surface of the skin.

The particles of vapour are kept separate by the repellent force of the heat absorbed during the process of evaporation; but when this is overcome by the reduction of the temperature or by additional aqueous pressure, the particles tend to cohere again, and ultimately *condensation* takes place, the vapour assuming a visible form as fog, mist, or cloud, which are further condensed into rain or snow. The temperature at which aqueous vapour condenses is known as the *dew-point*.

103. **Dew—Fogs—Mists—Clouds.**—If a glass of iced water be brought into a warm room, the outside will be soon dimmed or bedewed with moisture. This moisture is derived from the condensation of a part of the aqueous vapour in the air in immediate contact with the vessel. The warm air in the room being saturated with moisture, the cold surface of the glass reduced the temperature of the air in contact with it, so that it was unable to hold as much moisture as before; part of the invisible vapour contained, therefore, is condensed and deposited in a thin film of water on the outside of the vessel. Dew is formed and deposited on the surface of the earth in exactly the same manner; for during the day the sun warms the surface of the earth (and indirectly the air also); and as during the day, hot summer days especially, evaporation is most active, the air is also well saturated with moisture. At night the heated surface cools

quickly, and consequently the air immediately in contact with it is also cooled. The result is that that part of the vapour which the cooled air is now unable to contain, is condensed and precipitated upon the surface in the form of *dew.* Dew is not deposited on all substances alike, but in proportion to the rapidity with which they lose or radiate their heat; or, in other words, dew is most copiously deposited on good radiators,—that is, those substances which part with their heat most rapidly, such as grass, leaves, wool, etc.,—and least on bad radiators, or those substances which lose their heat very slowly, such as rocks, metals, etc. This may be verified by actual observation, by noticing the shrubs in a garden and the gravel walks;—when the former are copiously bedewed, the latter will be found quite dry. The formation of dew, then, being thus due to radiation, it necessarily follows that whatever modifies radiation affects the formation and deposition of dew. Clouds, for instance, reflect the heat radiated from the surface back again; winds remove the air before it is sufficiently cooled. So that cloudy or windy nights are unfavourable to the deposition of dew; or if a tree or any other object, even a cobweb, overshadow the radiator, the process of radiation is intercepted, and the formation and deposition of dew effectually prevented. Under certain conditions the radiation of heat from the surface is so rapid as to reduce the air in contact with it below the freezing point, consequently the moisture is frozen and deposited in the form of *hoar-frost*, which is especially injurious to vegetation. In fact, radiation may be carried on so rapidly and to such an extent, that ice can be artificially formed even in tropical countries.

Fogs and *mists*, like dew, are also due to the condensation of the invisible aqueous vapour present in the air, but with this difference, that in the latter case the surface of the earth must become colder than the air, while in the former the reverse is the case. The words fog and mist are often used synonymously; but, strictly speaking, a fog is the first stage in the gradual condensation of aqueous vapour, while a mist may be said to be the second stage in the process, being indeed a fog still more condensed by cold, the third, fourth, and fifth stages being respectively clouds, rain, and snow. Fogs are prevalent in or near any considerable bodies of water, and most frequent in this country in winter and spring, being especially dense with easterly winds; this, most probably, being due to the abstraction of considerable quantities of vapour by the easterly current of air as it passes over the North Sea, the vapour being condensed again on coming in contact with the surface of the land. The meeting of the warm Gulf Stream with its humid air, and the iceberg-laden Labrador current with its cold air, is the cause of the constant dense fogs of Newfoundland. Broken and elevated coasts lying transversely to the general direction of the winds blowing from the ocean are also subject to heavy fogs, *e.g.* Norway and Peru. The fogs often seen over a river or lake are formed by the difference between the air over the water and that over the land on each side, and it is quite immaterial whether the former be warmer or whether it be colder than the latter. In the former case, the warmer air over a river or lake is condensed by the colder air on each side, and thus a fog is produced; and in the latter case, the same inequality of temperature produces the same results. The dense

November fogs of London are due to the proximity of the river, the artificial heat of the city, and the cold easterly winds prevalent, the condensed vapour being rendered still more dense by the admixture of smoke and other gases.

Clouds are also masses of partially condensed vapour; but, unlike mists or fogs, which are due to differences of temperature at or very near the surface, clouds are formed by the condensation of vapour at considerable elevations. If from any cause a reduction in the temperature of the air occurs, whether at the surface or at some elevation, the separation or partial condensation of the particles of vapour is the invariable result; in other words, the vapour, before invisible and transparent, becomes visible and opaque in the form of a mist or fog, if at or near the surface, and a cloud if at any considerable height. The same result also follows the meeting of two currents of air of different temperature and moisture. Mountain chains, by intercepting moist winds and condensing their vapour, are by far the most important cloud-formers in nature, the moist current from the heated plain below or from the warm surface of the sea being driven up the slope, until, coming into a much colder region, the vapour is condensed and appears as cloud. Sometimes, and in some particular places, certain clouds seem to be motionless and permanent, as in the Alps, or that on Table Mountain, near Cape Town. That the permanence of such clouds is merely apparent is thus shown by Professor Tyndall (*Forms of Water*):—'You frequently see a streamer of cloud many hundred yards in length drawn out from an alpine peak. Its steadiness appears perfect, though a strong wind may be blowing at the same time over the mountain head. Why is the cloud not blowing away? It *is* blown away; its permanence is only apparent. At one end it is incessantly dissolved, at the other end it is incessantly renewed; supply and consumption being thus equalized, the cloud appears as changeless as the mountain to which it seems to cling.' With these apparent exceptions, clouds are generally in motion, being swept along by the currents of air in which they are suspended, attaining sometimes a velocity of 70 or 100 miles an hour. In this country the height of the cloud region proper varies from 2000 to 6500 feet; in the trade-wind regions from 3000 to 5000 feet. In the latter, clouds attain a much greater height over the sea than over the land; in all other parts of the globe the reverse is the case. The *colour* of clouds varies from the white fleecy curl clouds through almost all the intermediate tints, as they reflect the sun's rays, to the almost black rain-cloud. How clouds are supported in the air is not as yet satisfactorily explained. Mr. Cooley supposes that the particles of mist or cloud carry off with them the negative electricity of the earth's surface, and that this electricity invests each globule with a small atmosphere of repulsion, which, acting on the air, has the effect of making the globule virtually occupy a space much exceeding its actual volume, thus rendering it buoyant.

As to *form*, it has been observed that although clouds apparently assume an endless and ever-changing variety of form, yet if closely observed they will be found to assume generally three characteristic and well-defined forms, named by Mr. Luke Howard the *cirrus* or curl cloud, the *cumulus* or summer cloud, and the *stratus* or fall cloud. By a combination of two of these primary forms, four secondary or compound forms are produced, viz.

the *cirro-stratus*, *cumulo-stratus*, *nimbus*, and *cirro-cumulus*. Of the primary forms, the *cirri* or curl clouds are the light fleecy clouds floating far above any other cloud. They are supposed to range in height from 3 to 10 miles, and therefore above the snow-line or limit of perpetual congelation. They must therefore be in a frozen state, most probably as minute snow-flakes or ice crystals. But the air at such elevations is very rare—so rare, indeed, that it is inexplicable how they are supported; and the supposition that they are the visible heads of columns of vapour ascending from the lower strata of the air, does not solve the difficulty, unless we go a step farther, and say that, granting the *cirri* are the visible heads of ascending columns of vapour, in our opinion the particles of vapour, having attained a certain elevation, are condensed, necessarily in a frozen state, and thus become visible. But how are these clouds, when formed, supported at such a height? We think that their permanence is only apparent, the congealed particles as soon as formed falling down again, but almost immediately liquefied and vaporized again in their descent, the apparent permanence being due to the fact that the supply is constant, and equal to the waste during the time they are visible; and as the supply decreases, and the waste still continues, they are ultimately dissolved and disappear. The *cumulus* or summer cloud is so called because of its massive appearance and its being most perfectly formed during the warm summer days. The cumulus is formed by currents of moist air ascending into colder regions of the air. The cloud begins to be formed soon after sunrise, floating at first very low; but as the heated current ascends, the cumulus is also carried upwards, attaining its greatest height a little after noon. As the ascending current gradually subsides as the sun's rays get more and more oblique, the cumulus descends into the lower strata of air, where it is finally dissipated either partially or entirely. Saussure suggested that the form of the cumulus, being exactly similar to that assumed when a coloured fluid is poured into clear water, proves beyond a doubt that its formation is due to the cooling of masses of moist air being poured, as it were, into the higher and colder regions of the air. The lowest of all clouds is the *stratus* or fall cloud, which is formed at night-*fall*, hence its name. This 'cloud of night' is formed by the condensation of the vapour given off from the surface of the earth during the day, and, descending as the temperature falls, ultimately forms dark bands stretching along the horizon. During the night the density of the stratus increases, but at dawn it is generally dissolved and disappears. As to the compound forms, we need only remark that they are simply combinations of two or more simple forms, and may therefore be easily distinguished. The *cirro-stratus* thus combine the characteristic forms of the cirrus and stratus; the *cirro-cumulus*, those of the cirrus and cumulus; the *cumulo-stratus*, those of the cumulus and stratus; and the *nimbus*, those of the cumulus, cirrus, and stratus, and hence often called *cumulo-cirro-stratus*. The nimbus is the true rain-cloud, generally low, scarcely ever above 5000 feet, and has a dull leaden appearance.

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