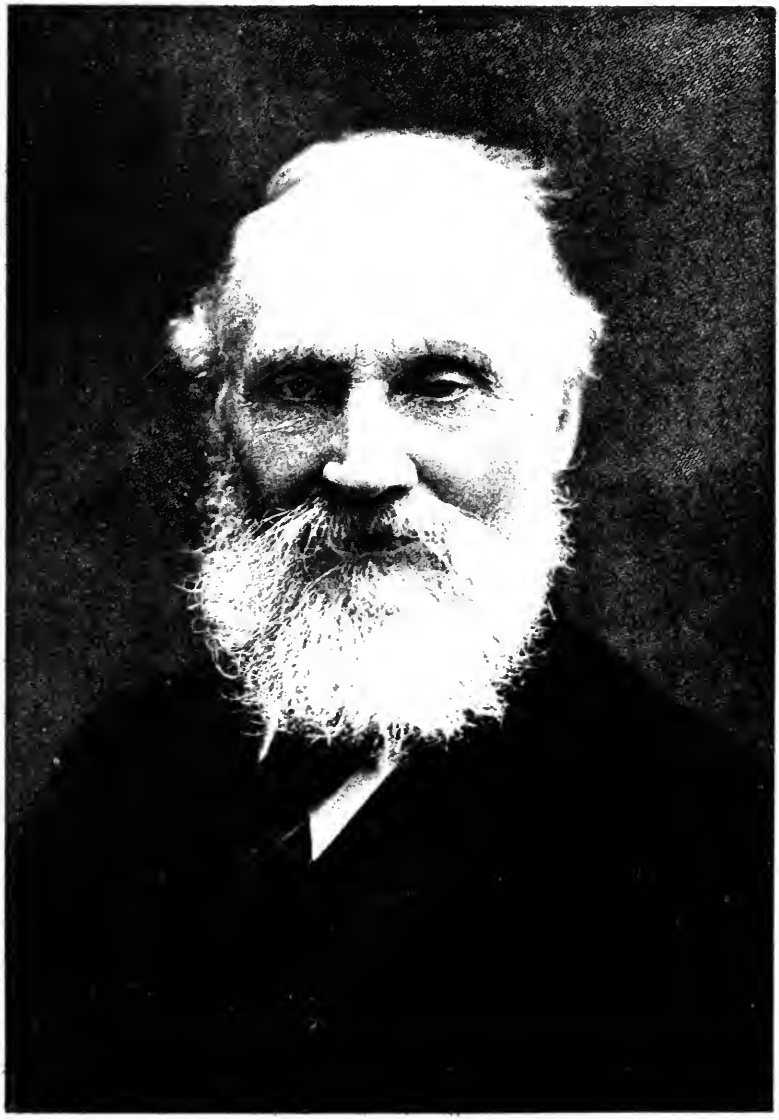

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Beacon Lights of Science

Modern Science and Modern Thought

By S. LAING

New York:
The Humboldt Library Association

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PREFACE TO FIRST EDITION.

THE object of this book is to give a clear and concise view of the principal results of Modern Science, and of the revolution which they have effected in Modern Thought. I do not pretend to discover fresh facts or to propound new theories, but simply to discharge the humbler though still useful task of presenting what has become the common property of thinking minds, in a popular shape, which may interest those who lack time and opportunity for studying special subjects in more complete and technical treatises.

I have endeavored also to give unity to the subjects treated of, by connecting them with leading ideas: in the case of Science, that of the gradual progress from human standards to those of almost infinite space and duration, and the prevalence of law throughout the universe to the exclusion of supernatural interference; in the case of Thought, the bearings of these discoveries on old creeds and philosophies, and on the practical conduct of life. The endeavor to show how much of religion can be saved from the shipwreck of theology has been the main object of the second part. Those who are acquainted with the scientific literature of the day will at once see how much I have been indebted to Darwin, Lyell, Lubbock, Huxley, Proctor, and other well-known writers. In fact, the first part of this book does not pretend to be more than a compendious popular abridgment of their works. I prefer, therefore, acknowledging my obligations to them once for all, rather than encumbering each page by detailed references.

The second part contains more of my own reflections on the important subjects discussed, and must stand or fall on its own merits rather than on authority. I can only say that I have endeavored to treat these subjects in a reverential spirit, and that the conclusions arrived at are the result of a conscientious and dispassionate endeavor to arrive at "the truth, the whole truth, and nothing but the truth."

S. Laing

Beacon Lights of Science

MODERN SCIENCE

AND

MODERN THOUGHT

CHAPTER I.

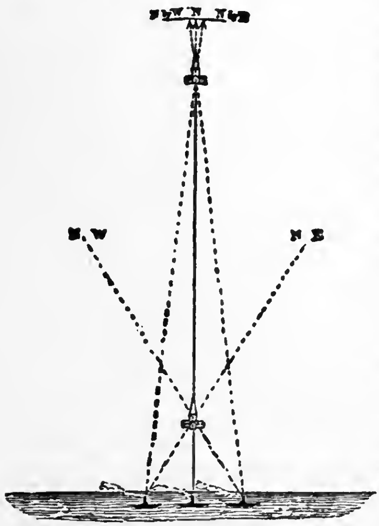
SPACE.

THE first ideas of space were naturally taken from the standard of man's own impressions. The inch, the foot, the cubit, were the lengths of portions of his own body, obviously adapted for measuring objects of comparatively small size with which he came in direct contact. The mile was the distance traversed in 1,000 double paces; the league the distance walked in an hour. The visible horizon suggested the idea that the earth was a flat, circular surface like a round table; and as experience showed that it extended beyond the limits of a single horizon, the conception was enlarged, and the size of the table increased so as to take in all the countries known to the geography of successive periods.

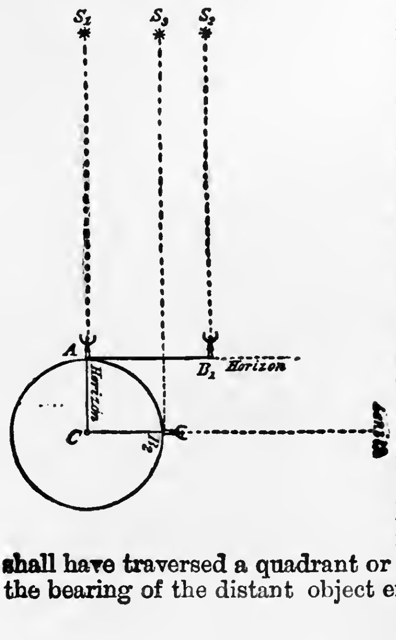
In like manner the sun, moon, and stars were taken to be at the distance at which they appeared; that is, first of the visible horizon, and then of the larger circle to which it had been found necessary to expand it. It was never doubted that they really revolved, as they seemed to do, round this flat earth circle, dipping under it in the west at night, and reappearing in the east with the day. The conception of the universe, therefore, was of a flat, circular earth surrounded by an ocean stream, in the centre of a crystal sphere which revolved in twenty-four hours round the earth, and in which the heavenly bodies were fixed as lights for man's use to distinguish days and seasons. The *maximum* idea of space was therefore determined by the size of the earth circle which was necessary to take in all the regions known at the time, with a little margin beyond for the ocean stream, and the space between it and the crystal vault, required to enable the latter to revolve freely. In the time of Homer and the early Greek philosophers, this would probably require a maximum of space of from 5,000 to 10,000 miles. This dimension has been expanded by modern science into one of as many millions, or rather hundreds of millions, as there were formerly single miles, and there is no sign that the limit has been reached.

How has this wonderful result been arrived at, and how do we feel certain that it is true? Those who wish thoroughly to understand it must study standard works on Astronomy, but it may be possible to give some clear idea of the processes by which it has been arrived at, and of the cogency of the reasoning by which we are compelled to accept facts so contrary to the first impressions of our natural senses.

The fundamental principle upon which all measurements of space depend, which are beyond the actual applicationtof human standards, is this: that distant objects change their bearings for a given change of base, more or less in proportion as they are less or more distant. Suppose I am on board a steamer sailing down the Thames, and I see two churches on the Essex coast directly opposite to me, or bearing due north, the first of which is one mile and the other ten miles distant. I sail one mile due east and again take the bearings. It is evident that the first church will now bear north-west, or have apparently moved through 45°, *i.e.*, one-eighth part of the circumference of a complete circle, assuming this circumference to be divided into 360 equal parts or degrees; while the more distant church will only have altered its bearing by a much less amount, easily determined by calculation, but which may be taken roughly at 5° instead of 45°.



The branch of mathematics known as Trigonometry enables us in all cases, without exception, where we know the apparent displacement or change of bearing of a distant object produced by taking it from the opposite ends of a known base, to calculate the distance of that object with as much ease and certainty as if we were working a simple sum of rule of three. The first step is to know our base, and for this purpose it is essential to know the size and form of the earth on which we live. These are determined by very simple considerations.



If I walk a mile in a straight line, an object at a vast distance like a star will not change its apparent place perceptibly. But if I walk the same distance in a semi-circle, what was originally on my left hand will now be on my right, or will have changed its apparent place by 180°. If I walk my mile on the circumference of a circle of twice the size, I shall have traversed a quadrant or one-fourth part of it, and changed the bearing of the distant object exactly half as much, or 90°, and so on, according to the size of the circle, which may therefore be readily calculated from the length that must be travelled along it to shift the bearing of the remote object by a given amount, say of 1°.

If, for instance, by travelling 65 miles from north to south we lower the apparent height of the Pole star 1°, it is mathematically certain that we have travelled this 65 miles, not along a flat surface, but along a circle which is 360 times 65, or, in round numbers, 24,000 miles in circumference and 8,000 miles in diameter. And if, whenever we travel the same distance on a meridian or line drawn on the circumference from north to south, we find the same displacement of 1°, we may be sure that our journey has been in a true circle, and that the form of the earth is a perfect sphere of these dimensions.

Now, this is very nearly what actually occurs when we apply methods of scientific accuracy to measure the earth. The true form of the earth is not exactly spherical, but slightly oval or flatter at the poles, being almost precisely the form it would have assumed if it had been a fluid mass rotating about a north and south axis. But it is very nearly spherical, the true polar diameter being 7,899 miles, and the true equatorial diameter 7,925 miles, so that for practical purposes we may say roughly that the earth is a spherical body, 24,000 miles round and 8,000 miles across.

This gives us a fresh standard from which to start in measuring greater distances. Precisely as we inferred the distance of the church from the steamer in our first illustration, we can infer the distance of the sun, from its displacement caused by observing it from two opposite ends of a base of known length on the earth's surface. This is the essential principle of all the calculations, though, when great accuracy is sought for, very refined methods of applying the principle are required, turning mainly on the extent to which the apparent occurrence of the same event—such as the transit of Venus over the sun's disc—is altered by observing it from different points at known distances from one another on the earth's surface. The result is to show that the sun's distance from the earth is, in round numbers, 93,000,000 miles. This is not an exact statement, for the earth's orbit is not an exact circle, but the sun and earth really revolve in ellipses about the common centre of gravity. The sun, however, is so much larger than the earth that this centre of gravity falls within the sun's surface, and, practically, the earth describes an ellipse about the sun, the 93,000,000 miles being the mean distance, and the eccentricity, or deviation from the exact circular orbit, being about one-sixtieth part of that mean distance. This distance, again, gives us the size of the sun, for it is easily calculated how large the sun must be to look as large as it does at a distance of 93,000,000 miles. The result is, that it is a sphere of about 880,000 miles in diameter. Its bulk, therefore, exceeds that of the earth in the proportion of 1,384,000 to 1. Its density, or the quantity of matter in it, may be calculated from the effect of its action on the earth under the law of gravity at the distance of 93,000,000 miles. It weighs as much as 354,936 earths.

The same method gives us the distance, size, and weight of the moon and planets; and it gives us a fresh standard or base from which to measure still greater distances. The distance of the earth from the sun being 93,000,000 miles, and its orbit an ellipse nearly circular, it follows that it is in mid-winter, in round numbers, 186,000,000 miles distant from the spot where it was at mid-summer. What difference in the bearings of the fixed stars is caused by traversing this enormous base?

The answer is, in the immense majority of cases, no difference at all; *i.e.*, their distance is so vastly greater than 186,000,000 miles that a change of base to this extent makes no change perceptible to the most refined instruments in their bearings as seen from the earth. But the perfection of modern instruments is such, that a change of even one second, or $\frac{1}{3600}$th part of one degree, in the annual parallax, as it is called, of any fixed star, would certainly be detected.

This corresponds to a distance of 206,265 times the length of the base of 186,000,000 miles, or of 20,000,000,000,000 miles, a distance which it would take light moving at the rate of 190,000 miles per second, three years and eighty-three day to traverse. There is only one star in the whole heavens, a bright star called Alpha, in the constellation of the Centaur, which is known to be as near as this. Its annual parallax is 0·976″, or very nearly 1″, and therefore its distance very nearly 20 millions of millions of miles. All the other stars, of which many millions are visible through powerful telescopes, are further off than this.

There are about eight other stars which have been supposed by astronomers to show some trace of an annual parallax of less than half a second, and therefore whose distances may be somewhere from twice to ten times as great as that of Alpha Centauri, and from the quantity of light sent to us from these distances, some approximation has been made to their intrinsic splendor as compared with our sun. That of Alpha Centauri is computed to be nearly 2½ times that of Sirius, the brightest star in the heavens, 393 times greater than that of the sun. These figures may or may not represent greater size or greater intensity of light, and they are only quoted to give some idea of the vastness of the scale of the universe, of which our solar system forms a minute part.

Nor does even this nearly fathom the depth of the abysses of space. Telescopes enable us to see a vast multitude of stars of varying size and brilliancy. It is computed by astronomers that there are at least one hundred millions of stars within the range of the telescopes used by Herschel for gauging the depth of space, and a thousand millions within the range of the great reflecting telescope of Lord Rosse. As many as eighteen different orders of magnitude have been counted, and the more the power of telescopes is increased the more stars are seen. Now, as there is no reason to suppose that this extreme variety of brilliancy arises from extreme difference of size of one star from another, it must be principally owing to difference of distance, so that a star of the eighteenth magnitude is presumably many times further off than any of the first magnitude, the distance of the nearest of which has been proved to be something certainly not less than 20,000,000,000,000 miles. In fact, these stellar distances are so great that in order to bring them at all within the range of human imagination we are obliged to apply another standard, that of the velocity of light. Light can be shown to travel at the rate of about 186 millions of miles in 16 minutes, for this is the difference of the time at which we see the same periodical occurrence, as for instance the eclipses of Jupiter's satellites, according as the earth happens to be at the point of its orbit nearest to Jupiter or at that farthest away. The velocity of light is therefore about 184,000 miles per second, a velocity which has been fully confirmed by direct experiments made on the earth's surface.

These enormous distances are reckoned, therefore, by the number of years which it would take light to come from them, travelling as it does at the rate of 184,000 miles a second. The nearest fixed star, Alpha Centauri, is seen by the ray which left it three years and eighty three days ago, and has been travelling ever since at the rate of 184,000 miles per second. Sirius, the brightest of the fixed stars, if the determination of its annual parallax is correct, is six times further off, and is seen, not as it exists to-day but as it existed nearly twenty years ago; and the light we now see from some of the stars of the eighteen magnitude can hardly have left them less than 2,000 years ago.

Even this, however, is far from exhausting our conception of the magnitude of space. Beyond the stars which are near enough to be seen separately, powerful telescopes show a galaxy in which the united lustre of myriads of stars is only perceptible as a faint nebulous gleam. And in addition to stars the telescope shows us a number of nebulæ, or faint patches of light, sometimes globular, sometimes in wreaths, spiral wisps, and other fantastic shapes, scattered about the heavens. Some of these are resolved by powerful telescopes into clusters of stars inconceivably numerous and remote, which appear to be separate universes, like that of which our sun and fixed stars form one. Others again cannot be so resolved, and are shown by the spectroscope to be enormous masses of glowing gas, or cosmic matter, out of which other universes are in process of formation.

We are thus led, step by step, to enlarge our ideas of space from the primitive conception of miles and leagues, until the imagination fails to grasp the infinite vastness of the scale upon which the material universe is really constructed.

If the telescope takes us thus far beyond the standards of unaided sense in the direction of the infinitely great, the microscope, aided by calculations as to the nature of light, heat, electricity, and chemical action, takes us as far in the opposite direction of the infinitely small. The microscope enables us actually to see magnitudes of the order of $\frac{1}{100,000}$th of an inch as clearly as the naked eye can see those of $\frac{1}{10}$th. This introduces us into a new world, where we can see a whole universe of things both dead and alive of whose existence our forefathers had no suspicion. A glass of water is seen to swarm with life, and be the abode of bacteria, amœbæ, rotifers, and other minute creatures, which dart about, feed, digest, and propagate their species in this small world of their own, very much as jelly-fish and other humble organisms do in the larger seas. The air also is shown to be full of innumerable germs and spores floating in it, and ready to be deposited and spring into life, wherever they find a seed-bed fitted to receive them. Given a favorable soil in the human frame, and the invisible seeds of scarlet fever, cholera, and small-pox ripen into full crops, just as the germs of a fungus invade the potato crops of a whole district, and lead to Irish famines and the extermination of more than a million of human beings.

The microscope also enables us to see the very beginnings of life and watch its primitive element, protoplasm, in the form of a minute speck of jelly-like matter, through which pulsations are constantly passing, and we can watch the transformations by which an elementary cell of this substance splits up, multiplies, and by a continued process of development builds up with these cells all the diversified forms of vegetable and animal life.

But far as the microscope carries us down to dimensions vastly smaller than those of which the ordinary senses can take cognizance, the modern sciences of light, heat, and chemistry carry us as much farther downwards, as the telescope carries us upwards beyond the boundaries of our solar system into the expanses of stars and nebulæ. We are transported into a world of atoms, molecules, and light-waves, where the standard of measurement is no longer in feet or inches, or even in one-hundred-thousandth part of an inch, but in millionths of millimetres, *i. e.*, in $\frac{1}{25,000,000,000}$th of an inch. The dimensions are such that, as we shall see when we come to deal with matter, if the drop of water in which the microscope shows us living animalcula were magnified to the size of the earth, the atoms of which it is composed would appear of a size intermediate between that of a rifle-bullet and a cricket-ball.

This, then, is Nature's scale of space, from millionths of a millimetre up to millions of millions of miles. Throughout the whole of this enormous range of space the laws of Nature prevail.

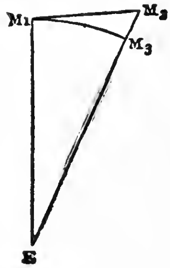
Matter attracts matter by the same law of gravity in the case of double stars revolving about each other at a distance at which a base of 180,000,000 miles has long since become a vanishing point, and in the case of atoms which form the substance of a gas, as in that of an apple falling from a tree at the earth's surface. Comets, darting off into the remote regions of space, return after long periods, in obedience to the same law. Clouds of meteoric dust revolve in fixed orbits, determined by the law of gravity as surely as the moon revolves round the earth, and the earth round the sun.

This is a conclusion of such fundamental importance that it is desirable to give the uninitiated reader some clear idea of what it means and how it is arrived at. Newton's great discovery, the law of gravity, is this—that all matter acting in the mass attracts other matter directly as the amount of attracting matter, and inversely as the square of the distance. That is, 2 or 2,000,000 tons attract with twice the force of 1 or 1,000,000 tons at the same distance, but with only one-fourth of the same force at double, and one-ninth at triple the distance.

How is this law proved? This will be best answered by explaining how it was discovered. The force of gravity, or attraction of the earth on bodies at the earth's surface, is a known quantity. The whole matter in a spherical body attracts exactly as if it were all collected at the centre. The force of gravity at the earth's surface is, therefore, that of the earth's mass exerted at a distance of about 4,000 miles, and this can be easily measured by observing the space fallen through, and the velocity acquired, by a falling body in a given time, such as 1″.

Does the same force act at the distance of the moon, or 207,200 miles? This was the question Newton asked himself, and the answer was got at in the following way. If we swing a stone in a sling round our head, it describes a circle as long as we keep the string tight, and its pull inwards just balances the pull of the stone to fly outwards, *i.e.*, to use scientific language, as long as the centripetal just balances the centrifugal force. But if we let go the string the stone darts off in the direction in which, and with the velocity with which, it was moving when the centripetal force ceased to act.

The moon is such a sling-stone revolving about the earth. At each instant it is moving in the direction of a tangent to its orbit, and would move on in a straight line along this tangent if it were not deflected from it by some other force. That is, if the moon were now at M_1, it would, after a given interval of time, be at M_2 if no force had acted on it. But in point of fact it is not at M_2 but at M_3. Therefore it has been pulled down from M_2 to M_3, or if you like, fallen through the space $M_2 M_3$ in the time in which it would have travelled over $M_1 M_2$ with its velocity at M_1. How does this space correspond with the space through which a heavy body would have fallen in the same time at the earth's surface? It corresponds exactly, assuming the law of gravity to be, that it decreases with the square of the distance.



This may be taken as the first approximation, but the more accurate and universal proofs of the law are derived from mathematical calculations of what the nature of the attractions must be, in the case of the sun, earth, moon, and planets, to make them describe such elliptic orbits and observe such laws, as from Kepler's observations we know actually to be the case. The answer here again is the law of gravity, and no other possible law, and this is confirmed in practice by the fact that we are able, by calculations based on it, to satisfy the requisite of safe prophecy—that of knowing beforehand, and to predict eclipses, comets, transits, and occultations, and generally to compile Nautical Almanacs, by which ships know their whereabouts in pathless oceans.

This, then, affords us a first firm standing-point in any speculations as to the nature of the universe. One great law, at any rate, is universal throughout all space, and, as we shall see later, suns, stars, and nebulæ are composed of the same matter as the earth and its inhabitants.

In like manner comets and meteors, though presenting in other respects phenomena not yet fully understood, are proved to obey the same laws and to consist of the same matter. Comets are bodies which revolve round the sun, and are attracted by it and by the planets, in obedience to the ordinary law of gravity, though their density is so slight, that although often of enormous volume, they produce no perceptible effect on the planets, even when entangled amidst the satellites of a planet, as Lascelles' comet was among those of Jupiter.

Their dimensions may be judged of when it is stated that the comet of 1811 had a tail 120 millions of miles in length and 15 millions of miles in diameter at the widest part, while the diameter of the nucleus was about 127,000 miles, or more than ten times that of the earth. In order that bodies of this magnitude, passing near the earth, should not affect its motion or change the length of the year by even a single second, their actual substance must be inconceivably rare. If the tail, for instance, of the comet of 1843 had consisted of the lightest substance known to us, hydrogen gas, its mass would have exceeded that of the sun, and every planet would have been dragged from its orbit. As Proctor says, therefore: "A jar-full of air would probably have outweighed hundreds of cubic miles of that vast appendage which blazed across the skies to the terror of the ignorant and superstitious."

The extreme tenuity of a comet's mass is also proved by the phenomenon of the tail, which, as the comet approaches the sun, is thrown out sometimes to a length of 90 millions of miles in a few hours. And what is remarkable, this tail is thrown out against the force of gravity by some repulsive force, probably electrical, so that it always points away from the sun. Thus a comet which approaches the sun with a tail behind it, will, after passing its perihelion, recede from the sun with its tail before it, and this although the tail may be of the length of 200 millions of miles as in the comet of 1843. In the course of a few hours, therefore, this enormous tail has been absorbed and a new one started out in an opposite direction. And yet, thin as the matter of comets must be, it obeys the common law of gravity, and whether the comet revolves in an orbit within that of the outer planets, or shoots off into the abysses of space and returns only after hundreds of years, its path is, at each instant, regulated by the same force as that which causes an apple to fall to the ground; and its matter, however attenuated, is ordinary matter, and does not consist of any unknown elements. The spectroscope shows that comets shine partly by reflected sunlight and partly by light of their own, the latter part being gaseous, and this gas, in most comets, contains carbon, hydrogen, and nitrogen, possibly also oxygen, in the form of hydrocarbons or marsh gas, cyanogen and possibly oxygen compounds of carbon. One comet has recently given the line of sodium, and the presence of iron is strongly suspected.

As regards meteors, which include shooting stars and aërolites, it has been long known, from actual masses which have fallen on the earth, that they are composed of terrestrial matter, principally of iron, which has been partially fused by the heat engendered by the fiction of the rapid passage through the air. The recurrence of brilliant displays at regular intervals, as for instance those of August and November, when the whole sky often seems alive with shooting stars, had also been noticed; but it was reserved for recent times to prove that these meteor streams are really composed of small planetary bodies revolving round the sun in fixed orbits by the force of gravity, and that their display, as seen by us, arises from the earth in its revolution round the sun happening to intersect some of these meteoric orbits, and the fiction of our atmosphere setting fire to and consuming the smaller meteors which appear as shooting stars. This shows the enormous number of meteors by which space must be tenanted. It is proved that the earth encounters more than a hundred meteor systems, but the chance of any one ring or system being intersected by the earth is extremely small, as the earth is such a minute speck in the whole sun-surrounding space of the solar system. On a scale on which the earth's orbit was represented by a circle of 10 feet diameter, the earth itself would be only about $\frac{1}{190}$th of an inch in diameter, so that if, as astronomers say, the earth encounters about a hundred meteor systems in the course of its annual revolution, space must swarm with an innumerable number of these minute bodies all revolving round the sun by the force of gravity.

Has this law of gravity been uniform through all time as it undoubtedly is through all space? We have every reason to believe so. The law of gravity, which is the foundation of most of what we call the natural laws of geological action, has certainly prevailed, as will be shown later, through the enormous periods of geological time, and far beyond this we can discern it operating in those astronomical changes by which cosmic matter has been condensed into nebulæ, nebulæ into suns throwing off planets, and planets throwing off satellites, as they cooled and contracted. We cannot speak with quite the same certainty of infinite time as we can of infinite space, for we have no telescopes to gauge the abysses of time, and no certain standards, like those of the known dimensions of our solar system, to apply to periods too vast for the imagination.

But we can say this with certainty, that the present law of gravity must have prevailed when the outermost planet of our system, Neptune, was condensed into a separate body and began revolving in its present orbit, and that it has continued to act ever since; while, as a matter of probability, it is as nearly certain as anything can be, that the law by which the apple falls to the ground is an original law of matter, and has existed as long as matter has existed.

It certainly extends through all space. Double stars at a distance exceeding 20 millions of millions of miles revolve round their common centre of gravity by this law. Atoms and molecules almost infinitely smaller than millionths of millimetres derive from it their specific weights with as much certainty as if they were pounds or hundredweights.

What space and matter really may be, we do not know, and if we attempt to reason about their essence and origin, or quit the region of science based on fact, we get into the misty realms of metaphysics, where, like Milton's fallen angels, we

> Find no end in wandering mazes lost.

But this we do know of a certainty, that be matter and space what they may, they are subject to this one, uniform, all-pervading law; and attract, have always attracted, and will always attract, directly as the mass of the attracting matter and inversely as the square of the distance in space at which the attraction acts.

CHAPTER II.

TIME.

GEOLOGY has done for time what astronomy has for space—it has expanded the limited ideas derived from natural impression and early tradition, into those of an almost infinite duration. This result is so important that it is desirable that all educated persons, without being professed geologists, should have some clear idea of the nature of the conclusions and of the evidences on which they rest.

This I will endeavor to give.

When we come to examine the structure of the earth—or rather of the outer crust of the earth which we inhabit—with the care and precision of scientific methods, we find that it is not of uniform composition, but consists mainly of distinct layers, or strata, lying one over the other. This is true not only of the larger beds, or distinct formations, but of the details of each formation, many of which are built up as regularly as the layers of the Great Pyramid, while others are made up of layers no thicker than the leaves of a book.

Now consider what this fact of stratification implies. In the first place it implies deposit from water, for there is no other agency by which materials can be sorted out and thrown down in horizontal layers, while this agency is now doing the same thing every day and all over the world. The Rhone flows into the lake of Geneva a turbid stream, and flows out of it as clear as crystal. All the matter it brings in is deposited at the bottom of the lake, and in course of time will fill it up. This deposit varies with every alternation of flood and drought; the river depositing sometimes boulders and coarse gravel, sometimes shingle, sand, or fine mud, and carrying this material sometimes to a greater and sometimes to a less distance, according to the velocity of the stream.

Ages hence, when the lake has been converted into dry land, it will be as certain, whenever a pit is dug or a well sunk in it, that it was the work of a river flowing into a lake, as it is to-day, when we can see them at work.

And what is true of the Rhone and the Lake of Geneva, is true on a larger scale of the Ganges, the Mississippi, and of every sea or ocean, with every river or torrent pouring into it.

Again, the sea is perpetually wearing away the coasts of all lands, and, where the cliffs are soft and the tides and currents strong, at a very rapid rate. The materials swallowed up are rolled as shingle, ground into sand, or floated as fine mud, and all finally assorted and laid down at the bottom of the sea, not in a confused heap, but in regular succession. On some of them, shell-fish and other marine creatures live and die for generations, and their remains are covered over by fresh sands or clays, and preserved for future geologists. All this is going on now, and when we examine the rocks we find that precisely the same sort of thing has been going on from the newest to the oldest strata. With the exception of a comparatively small amount of igneous rock, which has boiled up from deep sources of molten matter, and been poured out in sheets of lava, or masses of trap, porphyry, and granite, according to the amount of pressure it has undergone and the time it has taken to cool and crystallize, all the earth's surface may be said to consist of stratified matter, showing clear signs of having been deposited from water. Some of the oldest rocks, such as gneiss, may be a little doubtful, as they have clearly been subjected to great heat under great pressure, until they became plastic enough to crystallize as they cooled, and thus destroy any fossils embedded in them and obliterate most of the ordinary signs of stratification. But the opinion of the best geologists is that they were originally stratified, and have become what is called "metamorphic," or changed by heat and pressure into the semblance of igneous rocks. But even if these are not included, enough remains to justify the general assertion that the outer crust of the earth, as known to us, is made up mainly of stratified materials which have been deposited from water.

Now this implies another most important fact, viz., that there must have been waste or denudation of existing land corresponding to the deposit of stratified materials under water. Water cannot generate these materials, and every square mile of such strata, say 10 feet thick, implies the removal of 10 feet from a square mile of land surface by rains and rivers, or of an equivalent amount of cubical content in some other way, as by the erosion of a coast line. This is a very important consideration when we come to estimate the time required for the formation of such a thickness of stratified beds as we find existing. There must have been a fundamental crystalline rock as the earth cooled down from a fluid state and acquired a solid crust, and this rock must have been worn down by primeval seas and rivers as the progressive cooling admitted of the condensation of aqueous vapor into water. The waste of this primitive crust must have been deposited in strata at the bottom of those seas in thick masses, covering the original rock, and these again must have been partly crystallized by heat and pressure, and over and over again upheaved and submerged, and themselves worn down by fresh erosion, forming fresh deposits which underwent a repetition of the same process.

A third important inference from the fact of stratification is that all strata must have been originally deposited horizontally, or very nearly so, and in such order that the lowest is the oldest.

Suppose we fill a jar with water, and put some white sand into it, and when that has subsided to the bottom and the water is clear, some yellow sand, and again some red sand, it is clear that we shall have at the bottom of the jar three horizontal deposits or strata, one white, one yellow, and one red, and that by no conceivable means can the order in which they were deposited have been other than first white, secondly yellow, and lastly red. This law, therefore, is invariable, that wherever it is possible to trace a series of strata lying one above the other, the lowest is the oldest, and the highest the youngest in point of time.

If, therefore, all the great formations, from the old Laurentian up to the newest Tertiary, had been deposited uniformly all over the world, and had remained undisturbed, and we could have seen them in one vertical section in a cliff twenty-five miles high—for that is about their total known thickness—we should have been able without further difficulty to determine their order of succession and respective magnitudes.

But this is plainly impossible, for the deposits going on at any one time are of very different character. For instance, we have at present the Globigerina ooze gradually filling the depths of the Atlantic with a deposit resembling chalk; the Gulfs of Bengal and Mexico silting up with fine clay from river deposits; vast tracts in the Pacific, Indian Ocean, and Red Sea, covered with coral and the *débris* of coral-reefs. How could these, if upheaved into dry land and explored by future geologists, be identified as having been formed contemporaneously?

Suppose that coins of Victoria had been dropped in each of them, the geologist who discovered these coins would have no difficulty in concluding that the strata in which they were found were all formed in the nineteenth century. The petrified shells and other remains found in geological strata are such coins. Every great formation has had its own characteristic fauna and flora, or aggregate of animal and vegetable life, varying slowly from one geological age to another, and linked to the past and future by some persistent types and forms, but still with such a preponderance of characteristic fossils as to enable us to assign the rocks in which they occur to their proper place in the volume of the geological record. Innumerable observations have shown that we can rely, with absolute confidence, on the fossils embedded in the different strata of the earth's crust as tests of the period to which they belong, however different the strata may be in mineral composition.

The next question is how we can ascertain the thickness and order of succession of these strata. We have seen that all stratified rocks were originally deposited from water and therefore horizontally. Had they remained so, in the first place the process of forming stratified rocks must long ago have come to an end, for all the land surface must have been worn down to the sea level, and with no more land to be denuded, deposition must have ceased at an early period of the earth's history. And, in the second place, we could have known nothing more of the earth's crust than we saw on the surface, and in the shallow pits and borings we could sink below it. But earthquakes and volcanoes, and the various fractures and pressures due to subterranean heat and secular contraction and cooling, have been at work counteracting the effects of denudation, and causing elevations and depressions by which the inequalities of the earth's surface have been renewed, the balance between sea and land maintained, and strata, originally horizontal at the bottom of the ocean, upheaved until sea-shells are found at the top of high mountains, and we can walk for miles over their upturned edges.

Any one who wishes to understand how geologists have been able to measure such a thickness of the earth's crust, has only to take a book open at page 1 and lay it flat before him. He can see nothing but that one page; but if he turns up the pages on the right-hand side of the book until their edges become horizontal, he can pass over them and count perhaps 500 pages in the space of a couple of inches.

This is precisely what geologists have been able to do at various points of the earth's surface where the upturned edges of the pages of its history are exposed, and they come out, one behind the other, in the due succession in which they were written by Nature. For instance, in travelling from east to west in England we pass continually from newer to older formations—Chalk comes in from below Tertiary; Oolite and Lias from below Chalk; then Permian or New Red Sandstone; Carboniferous, including the Coal measures; Devonian or Old Red Sandstone; Silurian, Cambrian, and in the extreme north-west of Scotland and the Hebrides, oldest of all the Laurentian.

There are some omissions and interpolations, but, in a general way, it may be said that within the bounds of the British Empire we have such a view of Nature's volume as would be got, in the case I have supposed, by travelling over its upturned edges from page 1 to page 500. And if each of the great formations be taken as a separate chapter, each chapter will be found to be made up of a number of pages, each with its own letter-press and illustrations, though connected with the pages before and after it by the thread of the continuous common subject of their proper chapter; as the chapters again are connected by the continuous common subject-matter of the complete volume. It must not be supposed that the volume is anything like perfect. We have to piece it together from fragments found in the limited number of countries which have thus far been scientifically explored, and which do not constitute more than a small part of the earth's surface. We know nothing of what is below the oceans which cover three-fourths of that surface, and there are great gaps in the record during times when portions of the surface were dry land, and consequently no deposit of strata or preservation of fossils was possible. Still a great deal has been accomplished, and the general result, as given by common consent of the best geologists, is as follows:

The total thickness of known strata is about 130,000 feet or twenty-five miles, or the $\frac{1}{160}$th part of the distance from the earth's surface to its centre. Of this, about 30,000 feet belong to the Laurentian, which is the oldest known stratified deposit; 18,000 to the Cambrian, and

22,000 to the Silurian. These form together what is known as the Primary or Palæozoic Epoch.

In the lowest, the Laurentian, the only faint trace of life discovered is that of the Eozoon Canadense, which is considered to be an undoubted petrifaction of a foraminiferous living organism with a chambered shell.

It must be remembered, however, that these earliest formations have been so changed by slow crystallization under great heat and pressure that all fossils and nearly all traces of stratification must have been obliterated.

In the Cambrian and Lower Silurian traces of life become more frequent, especially of low forms of sea-weeds, and in the Upper Silurian we find an abundance of life, consisting of crustacea, shell-fish, and a few true fish in the upper strata. Some of these shells, as the Lingula, have continued without much change up to the present time; and on the whole we find ourselves in the Silurian period, if not earlier, in presence of a state of things in which substantially present causes operated and present conditions were in force. Rains fell, winds blew, rivers ran, waves eroded cliffs, shell-fish lived and died, and crabs and sand-worms crawled about on shores left dry by each tide, very much as is the case at present.

The next great divison, which got the name of Primary before the existence of fossils was known in the older or Palæozoic division, comprises the Devonian or Old Red Sandstone; the Carboniferous which includes the coal; and the Permian or New Red Sandstone. The average thickness of these three systems taken together is about 42,000 feet. It may be called the era of Fern Forests and of Fish, the former being the principal source of our supplies of coal, and the latter being extremely abundant within the Devonian and Permian formations.

The third great division is formed by the Secondary group, which includes the Triassic, the Jura, and the Cretaceous or Chalk systems, and has an average thickness of about 15,000 feet. This epoch is emphatically the age of Reptiles as the preceding one was that of Fish, and the prevailing vegetation is no longer one of ferns and mosses, but of Gymnosperms, or plants having naked seeds, the most important class of which is that of the Coniferæ or Pine tribe. During this period the Plesiosauri, Ichthyosauri, and other gigantic sea-dragons abounded in the oceans; colossal land-dragons, such as the Dinosauri, occupied the continents, and Pterodactyls, a remarkable form of carnivorous flying lizards, ruled the air. Swarms of other reptiles, nearly related to the present lizards, crocodiles, and turtles, abounded both in the sea and land. A few traces of mammals and birds show that these orders had then come into existence, just as a few traces of reptiles are found in the Primary and of fish in the Palæozoic strata, but the few mammalian remains found are of small animals of the marsupial or lowest type, and the birds are of a transition type between reptiles and true birds. This epoch concludes with the Chalk formation, which is one of deep-sea deposit, where no trace of terrestrial life can be expected.

Above this comes the Tertiary epoch, when the present order, both of vegetable and animal life, is fairly inaugurated; mammals predominate over other forms of vertebrate animals; existing order, and species begin to appear and increase rapidly; and vegetation consists mainly of Angiosperms, or plants with covered seeds, as in our present forests. The total thickness of these strata, from the lowest or Eocene, to the end of the uppermost or Pliocene, is about 3,000 feet. Above this comes the Quarternary, or recent period, which comprises the superficial strata of modern formation, and is characterized by the undoubted existence of man and of animal species, which either now exist or have become extinct in quite recent geological times.

The details of this and of the Tertiary Epoch will be more fully considered when we come to treat of the antiquity of man, with which they are closely connected. But for the present object, which is that of ascertaining some standard of time for the immense series of ages proved by geology to have elapsed since the earth assumed its present condition, became subject to existing laws and fitted to be the abode of life, it will be sufficient to refer to the older strata.

The best idea of the enormous intervals of time required for geological changes will be derived from the coal measures. These consist of part only of one geological formation known as the Carboniferous. They are made up of sheets or seams of condensed vegetable matter, varying in thickness from less than an inch to as much as thirty feet, and lying one above another, separated by beds of rocks of various composition. As a rule, every seam of coal rests upon a bed of clay, known as the "under-clay," and is covered by a bed of sandstone or shale. These alternations of clay, coal, and rock, are often repeated a great many times, and in some sections in South Wales and Nova Scotia, there are as many as eighty or a hundred seams of coal, each with its own under-clay below and sandstone or shale above. Some of the coal seams are as much as thirty feet thick, and the total thickness of the coal measures is, in some cases, as much as 14,000 feet.

Now consider what these facts mean. Every under-clay was clearly once a surface soil on which the forest vegetation grew, whose accumulated *débris* forms the overlying seam of coal. The under-clays are full of the fibres of roots, and the stools of trees which once grew on them, are constantly found *in situ*, with their roots attached just as they stood when the tree fell, and added to the accumulation of vegetable matter, which in modern times forms peat, and in more ancient days, under different conditions of heat and pressure, took the more consolidated form of coal.

When these vegetable remains are examined with the aid of the microscope it is found that these ancient forests consisted mainly of trees like gigantic club-mosses, mares'-tails, and tree ferns, with a few resembling yews and firs. But in many cases the bulk of the coal is composed of the spores and seeds of these ferns and club-mosses, which were ripened and shed every year, and gradually accumulated into a vegetable mould, just as fallen leaves, beech-mast, and other *débris* gradually form a soil in our existing forests.

The time required must have been very great to accumulate vegetable matter, principally composed of fine spore dust, to a depth sufficient under great compression to give even a foot of solid coal. Dr. Dawson, who has devoted great attention to the coal-fields of America, says: "We may safely assert that every foot of thickness of pure bituminous coal implies the quiet growth and fall of at least fifty generations of Sigillaria, and therefore an undisturbed condition of forest growth, enduring through many centuries." But this is only the first step in the measure of the time required for the formation of the coal measures. Each seam of coal is, as we have seen, covered by a bed of sand or shale, *i. e.*, of water-borne materials. How can this be accounted for? Evidently in one way only—that the land surface in which the forest grew subsided gradually until it became first a marsh, and then a lagoon or shallow estuary, which silted up by degrees with deposits of sand or mud, and, finally, was upraised until its surface became dry land, in which a second forest grew, whose *débris* formed a second coal seam. And so on, over and over again, until the whole series of coal measures had been accumulated, when this alternation of slight submergences and slight rises came to an end, and some more decided movement of the earth's surface in the locality brought on a different state of things. This is in fact exactly what we see taking place on a smaller scale in recent times in such deposits as those of the delta of the Mississippi, where a well sunk at New Orleans passes through a succession of cypress swamps and forest growths, exactly like those now growing on the surface, which are piled one above the other, and separated by deposits of river silt, showing a long alternation of periods of rest when forests grew, followed by periods of subsidence when they were flooded and their remains were embedded in silt.

Starting on Dr. Dawson's assumption that one foot of coal represents fifty generations of coal plants, and that each generation of coal plants took ten years to come to maturity, an assumption which is certainly very moderate, and taking the actually measured thickness of the coal measures in some localities at 12,000 feet, Professor Huxley calculates that the time represented by the Coal formation alone would be six millions of years. Such a figure is, of course, only a rough approximation, but it is sufficient to show that when we come to deal with geological time, the standard by which we must measure is one of which the unit is a million of years.

This standard is confirmed by a variety of other considerations. Take the case of the Chalk formation.

Chalk is almost entirely composed of the microscopic shells of minute organisms, such as now float in the upper strata of our great oceans, and by their subsidence, in the form of an impalpable shell-dust, accumulate what is called the "Globigerina ooze," which is brought up by soundings in the Atlantic and Pacific from great depths. In fact, we may say that a chalk formation is now going on in the depths of existing oceans, and conversely that the old chalk, which now forms hills and elevated downs, was certainly deposited at the bottom of similar deep oceans of the Cretaceous period. The rate of deposit must have been extremely slow, certainly much slower than that of the deposit of the much grosser matter brought down by the Nile in its annual inundations, the growth of which has been estimated from actual measurement at about three inches per century. If one inch per century were the rate of accumulation of this microscopic shell-dust, subsiding slowly to depths of two or three miles over areas as large as Europe, it would take 1,200 years to form a foot of chalk, and 1,200,000 years to form 1,000 feet. Now there are places where the thickness of the Cretaceous formation, exposed by the edges of its upturned strata, exceeds 5,000 feet, so that this gives an approximation very similar to that furnished by the coal measures.

We have thus, on a rough approximation, a *minimum* period of about 6,000,000 years for the accumulation of a single member of one of the separate formations into which the total 130,000 feet of measured strata are subdivided. But this takes no account of the long periods during which no accumulation took place at the localities in question, and of the long pauses which must have ensued between each movement of elevation and submergence, and especially between the disappearance of an old and appearance of an almost entirely new epoch, with different forms of animal and vegetable life. We may be certain also that we are far from knowing the total thickness of strata which will be disclosed when the whole surface of the earth comes to be explored. All we can say is that we have fragmentary pages left in the geological record for, at the very least, 100 millions of years, and that probably the lost pages are quite as numerous as those of which we have an imperfect knowledge.

Sir Charles Lyell, the highest authority on the subject, is inclined to estimate the *minimum* of geological time at 200 millions of years, and few geologists will say that his estimate appears excessive.

Another test of the vast duration of geological time is afforded by the oscillations of the earth's surface. At first sight we are apt to consider the earth as the stable and the sea as the unstable element. But in reality it is exactly the reverse. Land has been perpetually rising and falling while the level of the sea has remained the same. This is easily proved by the presence of sea-shells and other marine remains in strata which now form high mountains. In the case of chalk, for instance, there must have been in England a change of relative level of sea and land or more than two miles of vertical height, between the original formation of the chalk at the bottom of a deep ocean and its present position in the North and South Downs. In other cases the change of level is even more conspicuous. The Nummulite limestone, which is formed like chalk from an accumulation of the minute shells of low organisms floating in the oceans of the early Tertiary period, is found in mountain masses, and has been elevated to a height of 10,000 feet and more in the Alps and Himalayas.

On a smaller scale, and in more recent times, raised beaches with existing shells and lines of cliffs and caves, are found at various heights above the existing sea-level of many of the coasts of Britain, Scandinavia, Italy, South America, and other countries.

Now the first question is, were these changes caused by the land rising or by the sea falling? The answer is, by the land rising Had they been caused by the sea standing at a higher level it must have stood everywhere at this level, at any rate in the same hemisphere and anywhere near the same latitude. But there are large tracts of land which have never been submerged since remote geological periods; and in recent times there is conclusive evidence that the changes of level of sea and land have been partial and not general. Thus in the well-known instance of the columns of the ruined temple of Serapis at Pozzuoli in the Bay of Naples, which forms the illustration on the title-page of Lyell's "Principles of Geology," there can be no doubt that since the temple was built, either the sea must have risen and since fallen, or the land sunk and since risen, at least twenty feet since the temple was built less than 2,000 years ago, for up to this height the marble columns are riddled by borings of marine shells, whose valves are still to be seen in the holes they excavated. But an elevation of the level of the Mediterranean of twenty feet would have submerged a great part of Egypt, and other low-lying lands on the borders of that sea, where we know that no such irruptions of salt water have taken place within historical, or even within recent geological times.

The conclusion is therefore certain, that the land at this particular spot must have sunk twenty feet, and again risen as much, so as to bring back the floor of the temple to its present position, which stood one hundred years ago just above the sea-level, and that so gradually as not to throw down the three columns which are still standing. A slow subsidence has since set in and is now going on, so that the floor is now two or three feet below the sea-level.

Similar proofs may be multiplied to any extent. Along the coasts of the British Islands we find, in some places submarine forests showing subsidence, in others raised beaches showing elevation, but they are not continuous at the same level. Along the east coast of Scotland there is a remarkable raised beach at a level of about twenty-four feet above the present one, showing in many places lines of cliff, sea-worn caves, and outlying stacks and skerries, exactly like those of the present coast, though with green fields or sandy links at their base, instead of the waves of the German Ocean. But as we go north this inland cliff gets lower and gradually dies out, and when we get into the extreme north, among the Orkney and Shetland Islands, there are no signs of raised beaches, and everything points towards the recent period having been one of subsidence.

Again, in Sweden, where marks were cut in rocks in sheltered situations on the tideless Baltic more than a century ago, so as to test the question of an alleged elevation of the land, it has been clearly shown that, in the extreme north of Sweden, the marks have risen nearly seven feet, while in the central portion of the country they have neither risen nor fallen, and in the southern province of Scania they have fallen.

This would be clearly impossible if the sea and not the land had been the unstable element, and apparent elevations and depressions had been due to a general fall or rise in the level of all the seas of the northern hemisphere.

In fact, the more we study geology the more we are impressed with the fact that the normal state of the earth is, and has always been, one of incessant changes. Water, raised by evaporation from the seas, falls as rain or snow on land, wastes it away and carries it down from higher to lower levels, to be ultimately deposited at the bottom of the sea. This goes on constantly, and if there were no compensating action, as the seas cover a much larger area than the lands, all land would ultimately disappear, and one universal ocean cover the globe. But inward heat supplies the compensating action, and new lands rise and new mountain chains are upheaved to supply the place of those which disappear.

This inward heat of the earth is not a mere theory but an ascertained fact; for as we descend from the surface in deep mines or borings, we find the temperature actually does increase at a rate which varies somewhat in different localities, but which averages about 1° Fahrenheit for every 60 feet of depth. At this rate of increase water would boil at a depth of 10,000 feet, and iron and all other metals be melted before we reached 100,000 feet. What actually occurs at great depths we do not know with any certainty, for we are not sufficiently acquainted with the laws under which matter may behave when under enormous heat combined with enormous pressure. But we do know from volcanoes and earthquakes that masses of molten rocks and of imprisoned gases exist in certain localities, at depths below the surface which, although large compared with our deepest pits, are almost infinitesimally small compared with the total depth of 4,000 miles from that surface to the earth's centre.

This much is clear, that, in order to account for observed facts, we must consider the extreme outer crust, or surface of the earth as known to us, as resting on something which is liable to expand and contract slowly with variations of heat, and occasionally, when the tension becomes great, to give violent shocks to the outer crust, sending earthquake waves through it, and to send up gases and molten lava through volcanoes, along lines of fissure, and at points of least resistance. It is clear, also, that these movements are not uniform, but that one part of the earth's surface may be rising while another is sinking, and portions of it may be slowly tilting over, so that as one end sinks the other rises.

The best comparison that can be made is to a sheet of ice which has been much skated over and cracked in numerous directions, so as to have become a sort of mosaic of ice fragment, which, when a thaw sets in and the ice gets sloppy, rise and fall with slightly different motions as a skater, gliding over them, varies the pressure, and occasionally give a crack and let water rise through from below in the line of fissure. The difficulty will not seem so great if we consider that the rocks which form the earth's crust are for the most part elastic, and that an amount of elevation which seems large in itself does not necessarily imply a very steep gradient. Thus, if the elevation which towards the close of the Glacial period carried a bed of existing sea-shells of Arctic type to the top of the hill, Moel Tryfen, in North Wales, which is 1,200 feet high, were, say one of 1,500 feet, this would be given by a gradient of 15 feet a mile, or 1 in 333 for 100 miles. Such a gradient would not be perceptible to the eye, and would certainly not be sufficient to cause any tension likely to rupture rocks or disturb strata.

Such movements are as a rule extremely slow. In volcanic regions there are occasionally shocks which raise extensive regions a few feet at a blow, and partial elevations and subsidences which throw up cones of lava and cinders, or let mountains down into chasms, in a single explosion. The most noted of these are the instances of Monte Nuovo, near Naples, 800 feet high, and Jorullo, in Mexico, thrown up in one eruption, and the disappearance the other day of a mountain 2,000 feet high in the Straits of Sunda during an earthquake. The largest rise recorded of an extensive area from the shock of an earthquake, is that which occured in South America in 1835, when a range of coast of 500 miles from Copiapo to Chiloe was permanently raised five or six feet by a single shock, as was shown by the beds of dead mussels and other shells which had been hoisted up in some places as much as ten feet. It is probable that the great chain of the Andes, whose highest summits reach 27,000 feet, has been raised in a great measure by a succession of similar shocks.

But for the most part these movements, whether of elevation or depression, go on so slowly and quietly that they escape observation

Scandinavia is apparently now rising and Greenland sinking, but most countries have remained appreciably steady, or nearly so, during the historical period. St. Michael's Mount, in Cornwall, is still connected with the mainland by a spit, dry at ebb tide and covered at flood, as it was more than 2,000 years ago when the old Britons carted their tin across to Phœnician traders. Egypt, during a period of 7,000 years, has preserved the same level, or at the most has sunk as slowly as the Nile mud has accumulated. Parts of the English and Scotch coast have risen perhaps twenty feet since the prehistoric period, when canoes were wrecked under what are now the streets of Glasgow, and whales were stranded in the Carse of Stirling. There is even some evidence that the latest rise may have occurred since the Roman wall was built from the Forth to the Clyde. In any case, however, the movements have been extremely slow, and there have been frequent oscillations, and long pauses when the level of land and sea remained stationary. The evidence, therefore, from the great changes which have occurred during each geological period, points to the same conclusion as that drawn from the thickness of formations, such as the coal measures and chalk, which must have been accumulated very slowly, viz., that geological time must be measured by a scale of millions of years.

Another test of the vast duration of geological time is afforded by the changes which have taken place in animal life as we pass from one formation to another, and even within the limits of the same formation. The fauna, or form of existing life at a given period, changes with extreme slowness. During the historical period there has been no perceptible change, and even since the Pliocene period, which cannot be placed at a less distance from us than 200,000 years, and probably at much more, the change has been very small. In the limited class of large land animals it has been considerable; but if we take the far more numerous forms of shell-fish and other marine life, the old species which have become extinct and the new ones which have appeared, do not exceed five per cent. of the whole. This is the more remarkable as great vicissitudes of climate and variations of sea-level have occurred during the interval. The whole of the Glacial period has come and gone, and Britain has been by turns an archipelago of frozen islands, and part of a continent extending over what is now the German Ocean, and pushing out into the Atlantic up to the one hundred fathom line.

Reasoning from these facts, assuming the rate of change in the forms of life to have been the same formerly, and summing up the many complete changes of fauna which have occurred during the separate geological formations, Lyell has arrived at the conclusion that geology requires a period of not less than 200 millions of years to account for the phenomena which it discloses.

Long as the record is of geological time, it is only that of one short chapter in the volume of the history of the universe. Geology only begins when the earth had cooled down into a state resembling the present; when winds blew, rains fell, rivers and seas eroded rocks and formed deposits, and when the conditions were such that life became possible by the remains of which those deposits can be identified.

But before this period began, which may be called that of the maturity or middle age of our planet, a much vaster time must be allowed for the contraction and cooling of the vaporous ether or cosmic matter of which it is formed, into the state in which the phenomena of geology became possible. And if vast in the case of the earth, how must vaster must be the life periods of the larger planets, such as Jupiter, which from their much greater size cool and contract much more slowly, and are not yet advanced beyond the stage of intense youthful heat and glowing luminosity which was left behind by our earth a great many tens of millions of years ago! And how vastly vaster must be that of the sun, whose mass and volume exceed those of Jupiter in a far higher ratio than Jupiter surpasses the earth!

And beyond all this in a third degree of vastness come the life periods of those stars or distant suns, which we know to be in some cases as much as three hundred times larger than our sun, and not nearly so far advanced as it in the process of emergence from the fiery nebulous into the solar stage.

To give some idea of the vast intervals of time required for these changes, a few facts and figures may be given.

One of the latest speculations of mathematical science is that the rotation of the earth is becoming slower, or in other words the day becoming longer, owing to the retarding action of the tides, which act as a brake on a revolving wheel. If so, mathematical calculation shows that the effect of the reaction on the moon of this action of the moon on the earth, must be that as the earth rotates more slowly, the moon recedes to a greater distance. And *vice versâ*, when the earth rotated more rapidly the moon was nearer to it, until at length, when the process is carried back far enough, we arrive at a time when the moon was at the earth's surface and the length of the day about three hours. In this state of things the moon is supposed to have been thrown off from the earth, either by one great convulsion, or, more probably, by small masses at a time forming a ring like that of Saturn, which ended by coalescing into a single satellite. With the moon, which is the principal cause of the tides, so much nearer the earth, their rise and fall must have been something enormous, and huge tidal waves like the bore of the Bay of Fundy, but perhaps 500 or 1,000 feet high, must have swept twice during each revolution of the earth on its axis, *i.e.*, twice every three or four hours, along all the narrower seas and channels and over all except the mountainous lands adjoining.

Now these conclusions may be true or not as regards phases of the earth's life prior to the Silurian period, from which downwards geology shows unmistakably that nothing of the sort, or in the least degree approaching to it, has occurred. But what I wish to point out is that all this superstructure of theory rests on a basis which really does admit of definite demonstration and calculation.

Halley found that when eclipses of the sun, recorded in ancient annals, are compared with recent observations, a discrepancy is discovered in the rate of the moon's motion, which must have been slightly slower then than it is now. Laplace apparently solved the difficulty by showing that this was an inevitable result of the law of gravity, when the varying eccentricity of the earth's orbit was properly taken into account; and the calculated amount of the variation from this cause was shown to be exactly what was required to reconcile the observations. But our great English mathematician, Adams, having recently gone over Laplace's calculations anew, discovered that some factors in the problem had been omitted, which reduced Laplace's acceleration of the moon's motion by about one-half, leaving the other half to be explained by a real increase in the length of the sidereal day, or time of one complete revolution of the earth about its axis. The retardation required is one sufficient to account for the total accumulated loss of an hour and a quarter in 2,000 years; or in other words, the length of the day is now more by about $\frac{1}{84}$th part of a second than it was 2,000 years ago.

At this rate it would require 168,000 years to make a difference of 1 second in the length of the day; 10,080,000 years for a difference of 1 minute; and 604,800,000 years for a difference of 1 hour. The rate would not be uniform for the past, for as the moon got nearer it would cause higher tides and more retardation; still, the abyss of time seems almost inconceivable to get back to the state in which the earth could have rotated in three hours and thrown off the moon.

It is right, however, to state that all mathematical calculations of time, based on the assumed rate at which cosmic matter cools into suns and planets, and these into solid and habitable globes, are in the highest degree uncertain. If the original data are right, mathematical calculation inevitably gives right conclusions. But if the data are wrong, or what is the same thing, partial and imperfect, the conclusions will, with equal certainty, be wrong also. Now in this case we certainly do not know "the truth, the whole truth, and nothing but the truth" respecting these processes. Take what is perhaps the most difficult problem presented by science—how the sun keeps up so uniformly the enormous amount of heat which it is constantly radiating into space. This radiation is going on in every direction, and the solar heat received by the earth is only that minute portion of it which is intercepted by our little speck of a planet. All the planets together receive less than one 230,000,000th part of the total heat radiated away by the sun and apparently lost in space. Knowing the amount of heat from the sun's rays received at the earth's surface in a given time, we can calculate the total amount of heat radiated from the sun in that time. It amounts to this, that the sun in each second of time parts with as much heat as would be given out by the burning of 16,436 millions of millions of tons of the best anthracite coal. And radiation certainly at this rate, if not a higher one, has been going on ever since the commencement of the geological record, which must certainly be reckoned by a great many tens of millions of years.

What an illustration does this afford of that apparent "waste of Nature" which made Tennyson "falter where he firmly trod" when he came to consider "her secret meaning in her deeds!"

Yet there can be no doubt that vast as these figures are, they are all the result of natural laws, just as we find the law of gravity prevailing throughout space at distances expressed by figures equally vast. The question is, what laws? The only one we know of at present at all adequate to account for such a generation of heat, is the transformation into heat of the enormous amount of mechanical force or energy, resulting from the condensation of the mass of nebulous matter from which the sun was formed, into a mass of its present dimensions. This is no doubt a true cause as far as it goes. It is true that as the mass contracts, heat would be, so to speak, squeezed out of it, very much as water is squeezed out of a wet sponge by compressing it. But it is a question whether it is the sole and sufficient cause. Mathematicians have calculated that even if we suppose the original cosmic matter to have had an infinite extension, its condensation into the present sum would only have been sufficient to keep up the actual supply of solar heat for about 15 millions of years. Of this a large portion must have been exhausted before the earth was formed as a separate planet, and had cooled down into a habitable globe. But even if we took the whole it would be altogether insufficient. All competent geologists are agreed in requiring at least 100 millions of years to account for the changes which have taken place in the earth's surface since the first dawn of life recorded in the older rocks.

Various attempts have been made to reconcile the discrepancy. For instance, it has been said that the constantly repeated impact of masses of meteoric and cometic matter falling into the sun must have caused the destruction of a vast amount of mechanical energy which would be converted into heat. This is true as far as it goes, but it is impossible to conceive of the sun as a target kept at a perpetual and uniform white heat for millions of years by a rain of meteoric bullets constantly fired upon it. More plausibly it is said that we know nothing of the interior constitution of the sun, and that its solid nucleus may be vastly more compressed than is inferred from the dimensions of its visible disc, which is composed of glowing flames and vapors. This also may be a true cause, but, after making every allowance, we must fall back on the statement that the continuance for such enormous periods of such an enormous waste of energy as is given out by the sun, though certainly explainable by laws of Nature, depends on laws not yet thoroughly understood and explained.

Even in the case, comparatively small and near to us, of the earth, the condition of the interior and the rate of secular cooling afford problems which as yet wait for solution. The result of a number of careful experiments in mines and deep sinkings shows that the temperature, as we descend below the shallow superficial crust which is affected by the seasons, *i. e.*, by the solar radiation, increases at the average rate of 1° Fahrenheit for every 60 feet of depth. That is the average rate, though it varies a good deal in different localities. Now, at this rate we should soon reach a depth at which all known substances would be melted.

But astronomical considerations, derived from the Precession of the Equinoxes, favor the idea that the earth is a solid and not a fluid body, and require us in any case to assume a rigid crust of not less than ninety miles in thickness. And if the whole earth below a thin superficial crust were in an ordinary state of fluidity from heat, it is difficult to see how it could do otherwise than boil, that is, establishing circulating currents throughout its mass with disengagement of vapor, in which case the surface crust must be very soon broken up and melted down, just as the superficial crust of a red-hot stream of lava is, if an infusion of fresh lava raises the stream below to white heat, or as a thin film of ice would be if boiling water were poured in below it.

All we can say is, that the laws under which matter behaves under conditions of heat, pressure, chemical action, and electricity so totally different as must prevail in the interior of the earth, and *á fortiori* in that of the sun, are as yet very partially known to us. In the meantime the safest course is to hold by those conclusions of geology which, as far as they go, depend on laws really known to us. For instance, the quantity of mud carried down in a year by the Ganges or Mississippi, is a quantity which can be calculated within certain approximate limits. We can tell with certainty how much the deposit of this amount of mud would raise an area, say of 100 square miles, and how long it would take, at this rate, to lower the area of India drained by the Ganges, a sufficient number of feet to give matter enough to fill up the Gulf of Bengal. And if among the older formations we find one, like the Wealden for instance, similar in character to that now forming by the Ganges, we can approximate from its thickness to the time that may have been required to form it.

In calculations of this sort there is no *theory,* they are based on positive facts, limited only by a certain possible amount of error either way. In short, the conclusions of geology, at any rate up to the Silurian period when the present order of things was fairly inaugurated, are approximate *facts* and not *theories,* while the astronomical conclusions are *theories* based on *data* so uncertain, that while in some cases they give results incredibly short, like that of 15 millions of years for the whole past process of the formation of the solar system, in others they give results almost incredibly long, as in that which supposes the moon to have been thrown off when the earth was rotating in three hours, while the utmost actual retardation claimed from observation would require 600 millions of years to make it rotate in twenty-three hours instead of twenty-four.

To one who looks at these discussions between geologists and astronomers not from the point of view of a specialist in either science, but from that of a dispassionate spectator, the safest course, in the present state of our knowledge, seems to be to assume that geology really proves the duration of the present order of things to have been somewhere over 100 millions of years, and that astronomy gives an enormous though unknown time beyond in the past, and to come in the future, for the birth, growth, maturity, decline, and death of the solar system of which our earth is a small planet now passing through the habitable phase.

So far, however, as the immediate object of this work is concerned, viz., the bearings of modern scientific discovery on modern thought, it is not very material whether the shortest or longest possible standards of time are adopted. The conclusions as to man's position in the universe and the historical truth or falsehood of old beliefs, are the same whether man has existed in a state of constant though slow progression for the last 50,000 years of a period of 15 millions, or for the last 500,000 years of a period of 150 millions. It is a matter of the deepest scientific interest to arrive at the truth, both as to the age of the solar system, the age of the earth as a body capable of supporting life, the successive orders and dates at which life actually appeared, and the manner and date of the appearance of the most highly organized form of life endowed with new capacities for developing reason and conscience in the form of Man. Those who wish to prove themselves worthy of their great good luck in having been born in a civilized country of the nineteenth century, and not in Palæolithic periods, will do well to show that curiosity, or appetite for knowledge, which mainly distinguishes the clever from the stupid and the civilized from the savage man, by studying the works of such writers as Lyell, Huxley, Tyndall, and Proctor, where they will find the questions here only briefly stated, developed at fuller length with the most accurate science and in the clearest and most attractive style. But for the moral, philosophical, and religious bearings of these discoveries on the current of modern thought, there is such a wide margin that it becomes almost immaterial whether the shortest possible or longest possible periods should be ultimately established.

CHAPTER III.

MATTER.

WHAT is the material universe composed of? Ether, Matter, and Energy. Ether is not actually known to us by any test of which the senses can take cognizance, but is a sort of mathematical substance which we are compelled to assume in order to account for the phenomena of light and heat. Light, as we have seen, radiates in all directions from a luminous centre, travelling at the rate of 184,000 miles per second. Now what is light? It is a sensation produced on the brain by something which has been concentrated by the lens of the eye on the retina, and then transmitted along the optic nerve to the brain, where it sets certain molecules vibrating. What is the *something* which produces this effect? Is it a succession of minute particles, shot like rifle-bullets from the luminous body and impinging on the retina as on a target? Or is it a succession of tiny waves breaking on the retina as the waves of the sea break on the shore? Analogy suggests the latter, for in the case of the sister sense, Sound, we know as a fact that the sensation is produced on the brain by waves of air concentrated by the ear, and striking on the auditory nerve. But we have a more conclusive proof. If one of a series of particles shot out like bullets overtakes another, the force of impact of the two is increased; but if one wave overtakes another when the crest of the pursuing wave just coincides with the hollow of the wave before it the effect is neutralized, and if the two are of equal size it will be exactly neutralized and both waves will be effaced. In other words, two lights will make darkness. This, therefore, affords an infallible test. If two lights can make darkness, light is propagated, like sound, by waves. Now two lights do constantly make darkness, as is proved every day by numerous experiments. Therefore light is caused by waves.

But to have waves there must be a medium through which the waves are propagated. Without water you could not have ocean waves; without air you could not have sound-waves. Waves are in fact nothing but the successive forms assumed by a set of particles which, when forced from a position of rest, tend to return to that position, and oscillate about it. Place a cork on the surface of a still pond, and then throw in a stone; what follows? Waves are propagated, which seem to travel outwards in circles, but if you watch the cork, you will see that it does not really travel outwards, but simply rises and falls in the same place. This is equally true of waves of sound and waves of light. But the velocity with which the waves travel depends on the nature of the medium. In a dense medium of imperfect elasticity they travel slowly, in a rare and elastic medium quickly. Now the velocity of a sound-wave in air is about 1,100 feet a second, that of the light-wave about 184,000 miles a second, or about one million times greater. It is proved by mathematical calculation that, if the density of two media are the same, their elasticities are in proportion to the squares of the velocities with which a wave travels. The elasticity of ether, therefore, would be a million million times greater than that of air, which, as we know, is measured by its power of resisting a pressure of about 15 lbs. to the square inch. But the ether must in fact be almost infinitely rare, as well as almost infinitely elastic, for it causes no perceptible retardation in the motions of the earth and planets. It must be almost infinitely rare also, because it permeates freely the interior of substances like glass and crystals, through which light-waves pass, showing that the atoms or ultimate particles of which these substances are composed, minute as they are, must be floating in ether like buoys floating on water or balloons in the air.

The dimensions of the light-waves which travel through this ether at the rate of 184,000 miles a second, can be accurately measured by strict mathematical calculations, depending mainly on the phenomena of interferences, *i.e.*, of the intervals required between successive waves for the crest of one to overtake the depression of another and thus make two lights produce darkness.

These calculations are much too intricate to admit of popular explanation, but they are as certain as those of the Nautical Almanac, based on the law of gravity, which enable ships to find their way across the pathless ocean, and they give the following results:

DIMENSIONS OF LIGHT-WAVES.

COLORS.	NUMBER OF WAVES IN ONE INCH.	NUMBER OF OSCILLATIONS IN ONE SECOND.
Red	39,000	477,000,000,000,000
Orange	42,000	506,000,000,000,000
Yellow	44,000	535,000,000,000,000
Green	47,000	575,000,000,000,000
Blue	51,000	622,000,000,000,000
Indigo	54,000	658,000,000,000,000
Violet	57,000	669,000,000,000,000

These are the colors whose vibrations affect the brain through the eye with the sensation of light, and which cause the sensation of white light when their different vibrations reach the eye simultaneously. But there are waves and vibrations on each side of these limits, which produce different effects, the longer waves with slower oscillations beyond the red, though no longer causing light causing heat, while the shorter and quicker waves beyond the violet cause chemical action, and are the most active agents in photography.

We must refer our readers to works treating specially of light for further details, and for an account of the vast variety of beautiful and interesting experiments with polarized light, colored rings, and otherwise, to which the theory of waves propagated through ether affords the key. For the present purpose it is sufficient to say that modern science compels us to assume, as the substratum of the material universe, such an ether extending everywhere, from the faintest star seen at a distance which requires thousands of years for its rays, travelling at the rate of 184,000 miles a second, to reach the earth, down to the infinitesimally small interspace between the atoms of the minutest matter. And throughout the whole of this enormous range law prevails, ether vibrates and has always vibrated in the same definite manner, just as air vibrates by definite laws when the strings of a piano are struck by the hammers.

I pass now to the consideration of matter.

What is matter? In the most general sense it is that which has weight, or is subject to the law of gravity. The next analysis shows that it is something which can exist in the three forms of solid, liquid, or gas, according to the amount of heat. Diminish heat, and the particles approach closer and are linked together by mutual attraction, so as not to be readily parted; this is a solid. Increase the heat up to a certain point, and the particles recede until their mutual attractions in the interior of the mass neutralize one another, so that the particles can move freely, though still held together as a mass by the sum of all these attractions acting as if concentrated at the centre of gravity; this is the liquid state. Increase the heat still more, and the particles separate until they get beyond the sphere of their mutual attraction and tend to dart off into space, unless confined by some surface on which they exert pressure; this is a gas.

The most familiar instance of this is afforded by water, which, as we all know, exists in the three forms of ice, water, and vapor or steam, according to the dose of heat which has been incorporated with it.

Pursuing our inquiry further, the next great fact in regard to matter is that it is not all uniform. While most of the common forms with which we are conversant are made up of mixed materials, which can be taken to pieces and shown separately, there are, as at present ascertained, some seventy-one substances which defy chemical analysis to decompose them, and must therefore be taken as elementary substances. A great majority of these consist of substances existing in minute quantities, and hardly known outside the laboratories of chemists.

The world of matter, as known to the senses, is mainly composed of combinations, more or less complex, of a few elements. Thus, water is a compound of two simple gases, oxygen and hydrogen; air, of oxygen and nitrogen; the solid framework of the earth, mainly of combinations of oxygen with carbon, calcium, aluminum, silicon, and a few other bases; salt, of chlorine and sodium; the vegetable world directly and the animal world indirectly, mainly of complex combinations of oxygen, hydrogen, and nitrogen with carbon, and with smaller quantities of silicon, sulphur, potassium, sodium, and phosphorus. The ordinary metals, such as iron, gold, silver, copper, tin, lead, mercury, zinc, nearly complete the list of what may be called ordinary elements.

Now let us push our analysis a step further, How is matter made up of these elements? Up to and beyond the furthest point visible by aid of the microscope, matter is divisible. We can break a crystal into fragments, or divide a drop into drops, until they cease to be visible, though still retaining all the properties of the original substance. Can we carry on this process indefinitely, and is matter composed of something that can be divided and subdivided into fractional parts *ad infinitum?* The answer is, No, it consists of ultimate but still definite particles which cannot be further subdivided. How is this known? Because we find by experience that substances will only combine in certain definite proportions either of weight or measure. For instance, in forming water exactly eight grains by weight of oxygen combine with exactly one grain of hydrogen, and if there is any excess or fractional part of either gas, it remains over in its original form uncombined.

In like manner, matter in the form of gas always combines with other matter in the same form by volumes which bear a definite and very simple proportion to each other, and the compound formed bears a definite and very simple ratio to the sum of the volumes of the combining gases. Thus two volumes of hydrogen combine with one of oxygen to form two volumes of water in the state of vapor.

From these facts certain inferences can be drawn. In the first place it is clear that matter really does consist of minute particles, which do not touch and form a continuous solid but are separated by intervals which increase with increase of temperature. This is evident from the fact that we can pour a second or third gas into a space already occupied by a first one. Each gas occupies the enclosed space just as if there were no other gas present, and exerts its own proper pressure on the containing vessel, so that the total pressure on it is exactly the sum of the partial pressures. It is easy to see what this means. If a second regiment can be marched into a limited space of ground on which a first regiment is already drawn up, it is evident that the first regiment must be drawn up in loose order, *i.e.*, the soldier-units of which it is composed must stand so far apart that other soldier-units can find room between them without disturbing the formation. But the effect will be that the fire from the front will be increased, as for instance if a soldier of the second regiment, armed with a six-shooter repeating rifle, takes his stand between two soldiers of the first regiment armed with single-barrelled rifles, the effective fire will be increased in the ratio of 8 to 2. And this is precisely what is meant by the statement that the pressure of two gases in the same space is the sum of the separate pressures of each. It is clearly established that the pressure of a gas on a containing surface is caused by the bombarding to which it is subjected from the impacts of an almost infinite number of these almost infinitely small atoms, which, when let loose from the mutual attractions which hold them together in the solid and fluid state, dart about in all directions, colliding with one another and rebounding, like a set of little billiard-balls gone mad, and producing a certain average resultant of momentum outwards which is called pressure.

Another simile may help us to conceive how the indivisibility of atoms is inferred from the fact that they only combine in definite proportions. Suppose a number of gentlemen and ladies promenading promiscuously in a room. The band strikes up a waltz, and they at once proceed to group themselves in couples rotating with rhythmical motion in definite orbits. Clearly, if there are more ladies than gentlemen, some of them will be left without partners. So, if instead of a waltz it were a threesome reel, in which each gentleman led out two ladies, there must be exactly twice as many ladies as gentlemen for all to join in the dance. But if a gentleman could be cut up into fractional parts, and each fraction developed into a dancing gentleman, as primitive cells split up and produce fresh cells, it would not matter how many ladies there were, as each could be provided with a partner. Now this is strictly analogous to what occurs in chemical combination. Water is formed by each gentleman atom of oxygen taking out a lady atom of hydrogen in each hand, and the sets thus formed commence to dance threesome reels in definite time and measure, any surplus oxygen or hydrogen atoms being left out in the cold. Wonderful as it may appear, science enables us not only to say of these inconceivably minute atoms that they have a real existence, but to count and weigh them. This fact has been accomplished by mathematical calculations based on laws which have been ascertained by a long series of experiments on the constitution of gases.

It is found that all substances, when in the form of gas, conform to three laws:

1. Their volume is inversely proportional to the pressure to which they are subjected.

2. Their volume is directly proportional to the temperature.

3. At the same pressure and temperature all gases have the same number of molecules in the same volume.

From the last law it is obvious that if equal volumes of two gases are of different weight, the cause must be that the molecules of the one are heavier than those of the other. This enables us to express the weight of the molecule of any other gas in some multiple of the unit afforded by the weight of the molecule of the lightest gas, which is hydrogen. Thus, the density of watery vapor being nine times that of hydrogen, we infer that the molecule of water weighs nine times as much as the molecule of hydrogen, and that of oxygen being eight times greater, we infer that the oxygen molecule is eight times heavier than that of hydrogen.

These weights are checked by the other law which has been stated, that chemical combination between different substances always takes place in certain definite proportions. Thus, whenever in a chemical process the original substances or the product are or might exist in the state of gas, it is always found that the definite proportions observed in the chemical process are either the proportions of the densities of the respective gases or some simple multiple of these proportions. Thus, the weight of hydrogen being 2, which combines with a weight of oxygen equal to 16 to form a weight of watery vapor equal to 18, the density of the latter is to that of hydrogen as 9 to 1, *i.e.*, as 18 to 2.

But to get to the bottom of the matter we must go a step further, and as we have decomposed substances into molecules, we must take the molecules themselves to pieces and see what they are made of. The molecule is the ultimate particle into which any substance can be divided retaining its own peculiar qualities. A molecule of water is as truly water as a drop or a tumblerful. But when chemical decomposition takes place, instead of the molecule of water we have molecules of two entirely different substances, oxygen and hydrogen. Nothing can well be more unlike than the product water and the component parts of which it is made up. Water is a fluid, oxygen a gas; water extinguishes fire, oxygen creates it. Water is a harmless drink, oxygen the base of the most corrosive acids. It is evident that the water-molecule is a composite, and that its qualities depend, not on the essential qualities of the atoms which have combined to make it, but on the manner of the combination, and the new modes of action into which these atoms have been forced. In his native war-paint oxygen is a furious savage; with a hydrogen atom in each hand he is a polished gentleman.

Our theory, therefore, leads beyond molecules to atoms, and we have to consider these particles of a still smaller order than molecules, as the ultimate indivisible units of matter of which we have been in search. And even these we must conceive of as corks, as it were, floating in an ocean of ether, causing waves in it by their own proper movements, and agitated by all the successive waves which vibrate through this ether-ocean in the form of light and heat.

Working on these data, a variety of refined mathematical calculations made by Clausius, Clark Maxwell, Sir W. Thomson, and other eminent mathematicians, have given us approximate figures for the actual size, weight, and velocities of atoms and molecules. The results are truly marvellous. A millimetre is the one thousandth part of a metre, or roughly one twenty-fifth of an inch. The magnitudes with which we have to deal are all of an order where the standard of measurement is expressed by the millionth part of a millimetre. The volume of a molecule of air is only a small fraction of that of a cube whose side would be the millionth of a millimetre. A cubic centimetre, or say a cube whose side is between one-third and one-half of an inch, contains 21,000,000,000,000,000,000 molecules. The number of impacts received by each molecule of air during one second will be 4,700 millions. The distance traversed between each impact averages 95 millionths of a millimetre.

It may assist in forming some conception of these almost infinitely small magnitudes, to quote an illustration given by Sir W. Thomson as the result of mathematical calculation. Suppose a drop of water were magnified so as to appear of the size of the earth or with a diameter of 8,000 miles, the atoms of which it is composed, magnified on the same scale, would appear of a size intermediate between that of a rifle-bullet and of a cricket-ball.

These figures show that space and magnitude extend beyond the standards of ordinary human sense, such as miles, feet, and inches, as far downwards into the region of the infinitely small as they do upwards into that of the infinitely great.

And throughout the whole of this enormous range law prevails. The same law of gravity gives weight to molecules and atoms, makes an apple fall to the ground, and causes double stars to revolve round their centre of gravity in elliptic orbits. The law of polarity which converts iron-filings into small magnets under the influence of a permanent magnet or electric current, animates the smallest atom. Atoms arrange themselves into molecules, and molecules into crystals, very much as magnetized iron-filings arrange themselves into regular curves. And the great law seems to prevail universally throughout the material, as it does also throughout the moral world, that you cannot have a North without a South Pole, a positive without a negative, a right without a wrong; and that error consists mainly in what the poet calls "the falsehood of extremes"—that is, in allowing the attraction of one pole, or of one opinion, so to absorb us as to take no account of its opposite.

The universal prevalence of law has received wonderful confirmation of late years from the discovery made by the spectroscope that the sun, the planets, and the remotest stars are all composed of matter identical with that into which chemical analysis has resolved the constituent matter of the earth. This has been proved in the following way:

If a beam of light is admitted into a darkened room through a small hole or narrow slit, and a triangular piece of glass, called a prism, is interposed in its path, the image thrown on a screen is a rainbow-tinted streak, intersected by numerous fine dark lines, which is called a spectrum. If, instead of solar light, light from other luminous sources is similarly treated, it is found that all elementary substances have their peculiar spectra. Light from solid or liquid substances gives a continuous spectrum, light from gases or glowing vapors gives a spectrum of bright lines separated from each other, but always in definite positions according to the nature of the substance. The next great step in the discovery was that these bright lines become dark lines when a light of greater intensity, coming from a solid nucleus, is transmitted through an atmosphere of such gases or vapors. We can thus photograph the spectrum of glowing hydrogen, sodium, iron, or other substances, and placing it below a photograph of a solar or stellar spectrum, see if any of the dark lines of the latter correspond with the bright lines of the former. If they do we may be certain that these substances actually exist in the sun or star. It is, in fact, just the same thing as if we had been able to bring down a jar full of the solar or stellar matter and analyze it in our laboratories.

It is difficult to convey any adequate description of these grand discoveries made by the new science of Spectroscopy without referring to special works on the subject; but it may be possible to give some general idea of the principles on which they are based.

Light consists of waves propagated through ether. These waves are started by the vibrations of the ultimate particles of matter, which, whether in the simplest form of atoms, in the more complex form of molecules, or in the still more complex form of compound molecules, have their own peculiar and distinct vibrations. These vibrations are increased, diminished, or otherwise modified by vibrations of heat and by the collisions which occur between the particles from their own proper motions. If we take the simplest case, that of matter in the form of a gas or vapor composed of single atoms, at a temperature just sufficient to become luminous and at a pressure small enough to keep the atoms widely apart, the vibrations are all of one sort, viz., that peculiar to the elementary substance to which they belong, and one set of waves only is propagated by them through the ether. The spectrum, therefore, of such a gas is a single line of light, in the definite position which is due to its refrangibility, *i.e.*, to the velocity of the particular wave of light which the particular vibration of those particular atoms is able to propagate.

When pressure is increased so that the particles are brought closer together, their vibrations made more energetic and their collisions more frequent, more waves, and waves of different qualities are started, and more lines appear in the spectrum and the lines widen out, until at length when the gas becomes very dense, some of the lines overlap and an approach is made towards a continuous spectrum. Finally, when the particles are brought so near together that the substance assumes a fluid or solid state, the number of wave-producing vibrations becomes so great that a complete system of different light-waves is propagated, and the lines of the spectrum are multiplied until they coalesce and form a continuous band of rainbow-tinted light. If the particles of the gas, instead of being single atoms, are more complex, as molecules or compound molecules, the vibrations are more complex and the different resulting light-waves more numerous, so that the lines in the spectrum are more numerous, and in some cases they coalesce so as to form shaded bands, or what are called fluted lines, instead of simple lines.

Moreover, whatever light-waves are originated by the vibrations of the particles of a gas are absorbed into those vibrations and extinguished, if they originate from the vibrations of some more energetic particles of another substance outside of it, whose light-waves, travelling along the ether, pass through the gas, and are thus shown as dark lines in the spectrum of the other source of light.

We can now understand how the assertion is justified that we can analyze the composition of the sun and stars as certainly as if we had a jar full of their substance to analyze in our laboratory. The first glance at a spectrum tells us whether the luminous source is solid, fluid, or gaseous. If its spectrum is continuous it is solid or fluid; we know this for certain, but can tell nothing more. But if it consists of bright lines, we know that it comes direct from matter in the form of luminous gas, and knowing from experiments in the laboratory the exact colors and situations of the lines formed by the different elements of which earthly matter is composed, we can see whether the lines in the spectra of heavenly matter do or do not correspond with any of them. If bright lines correspond we are sure that the substances correspond, both as to their elementary atoms and their condition as glowing gas. If dark lines in the spectrum of the heavenly body correspond with bright lines in that of a known earthly substance, we are certain that the substances are the same and in the same state of gas, but that the solar or stellar spectrum proceeds from an intensely heated interior solid or fluid nucleus, whose waves have passed through an outer envelope or atmosphere of this gas.

Applying these principles, although the science is still in its infancy and many interesting discoveries remain to be made, this grand discovery has become an axiomatic fact—Matter is alike everywhere. The light of stars up to the extreme boundary of the visible universe, is composed mainly of glowing hydrogen, the same identical hydrogen as we get by decomposing water by a voltaic battery.

Of the 71 elementary substances of earthly matter enumerated by chemists, 9 may be considered as doubtful or existing only in excessively minute quantities. Of the remaining 62, 22 are known certainly to exist in the sun's atmosphere, 10 more can probably be traced there, and there are only 6 as to which, in the present state of our knowledge, there is negative evidence that they are not present. The elements whose presence is proved comprise many of those which are most common in the composition of the earth, as hydrogen, iron, lead, calcium, aluminium, magnesium, sodium, potassium, etc.; and if others, such as oxygen, carbon, and chlorine have not yet been found, good reasons may be assigned why they may not exist in a state likely to give recognizable spectrum-lines. The main fact is firmly established that matter is the same throughout all space, from the minutest atom to the remotest star.

Thus far we have been treating of matter only, and of force and motion but incidentally. These, however, are equally essential components of the phenomena of the universe. What is force? In the last analysis it is the unknown cause which we assume for motion, or the term in which we sum up whatever produces or tends to produce it. The idea of force, like so many other of our ideas, is taken from our own sensations. If we lift a weight or bend a bow, we are conscious of doing so by an effort. Something which we call will produces a motion in the molecules of the brain, which is transmitted by the nerves to the muscles, where it liberates a certain amount of energy stored up by the chemical composition and decomposition of the atoms of food which we consume. This contracts the muscle, and the force of its contraction, transmitted by a system of pulleys and levers to the hand, lifts the weight. If we let go the weight it falls, and the force which lifted it reappears in the force with which it strikes the ground. If we do not let go the weight but place it on a support at the height to which we have raised it, it does not fall, no motion ensues, but the lifting force remains stored up in a tendency to motion, and can be made to reappear as motion at any time by withdrawing the support, when the weight will fall. It is evident, therefore, that force may exist in two forms, either as actually causing motion or as causing a tendency to motion.

In this generalized form it has been agreed to call it energy, as less liable to be obscured by the ordinary impressions attached to the word force, which are mainly derived from experiences of actual motion cognizable by the senses. We speak, therefore, of energy as of something which is the basis or *primum mobile* of all motion or tendency to motion, whether it be in the grosser forms of gravity and mechanical work, or in the subtler forms of moleculer and atomic motions causing the phenomena of heat, light, electricity, magnetism, and chemical action. This energy may exist either in the form of actual motion, when it is called energy of motion, or in that of tendency to motion, when it is called energy of position. Thus the bent bow has energy of position which, when the string is let go, is at once converted into energy of motion in the flight of the arrow.

Respecting this energy modern science has arrived at this grand generalization, that it is one and the same in all its different manifestations, and can neither be created nor destroyed, so that all these varied manifestations are mere transformations of the same primitive energy from one form to another. This is what is meant by the principle of the "Conservation of Energy."

It was arrived at in this way. Speaking roughly it has long been known that heat could generate mechanical power, as seen in the steam-engine; and conversely that mechanical power could generate heat, as is seen when a sailor, in a chill north-easter, claps his arms together on his breast to warm himself. But it was reserved for Dr. Joule to give this fact the scientific precision of a natural law, by actually measuring the amount of heat that was added to a given weight of water by a given expenditure of mechanical power, and conversely the amount of mechanical work that could be got from a given expenditure of heat.

A vast number of carefully-conducted experiments have led to the conclusion that if a kilogramme be allowed to fall through 424 metres and its motion be then suddenly stopped, sufficient heat will be generated to raise the temperature of one kilogramme of water by 1° Centigrade; and conversely this amount of heat would be sufficient to raise one kilogramme to a height of 424 metres.

If, therefore, we take as our unit of work that of raising one kilogramme one metre, and as our unit of heat that necessary to raise one kilogramme, of water 1° Centigrade, we may express the proportion of heat to work by saying that one unit of heat is equal to 424 units of work; or, as it is sometimes expressed, that the number 424 is the mechanical equivalent of heat.

But the question may be asked, what does this mean, how can mechanical work be really transformed into heat or *vice versâ?* The answer is, the energy which was supplied by chemical action to the muscles of the man or horse, or to the water converted into steam by combustion of coal, which originated the mechanical work, was first transformed into its equivalent amount of mechanical energy of motion, and then, when that motion was arrested, was transformed into heat, which is simply the same energy transformed into increased molecular motion.

If we wish to carry our inquiry a step further back and ask where the original energy came from which has undergone these transformations, the answer must be, mainly from the sun. The sun's rays, acting on the chlorophyl or green matter of the plants of the coal era, tore asunder the atoms of carbon and oxygen which formed the carbonic acid in the atmosphere, and locked up a store of energy in the form of carbon in the coal which is burned to produce the steam. In like manner it stored up the energy in the form of carbon in the vegetable products which, either directly, or indirectly after having passed through the body of some animal, supplied the food, whose slow combustion in the man or horse supplied the energy which did the work.

But where did the energy come from which the sun has been pouring forth for countless ages in the form of light and heat, and of which our earth only intercepts the minutest portion? This is a mystery not yet completely solved, but one real cause we can see, which has certainly operated and perhaps been the only one, viz., the mechanical energy of the condensation by gravity of the atoms which originally formed the nebulous matter out of which the sun was made. If we ask how came the atoms into existence endowed with this marvellous energy, we have reached the furthest bounds of human knowledge, and can only reply in the words of the poet: "Behind the veil, behind the veil."

We can only form metaphysical conceptions, or I might rather call them the vaguest guesses. One is, that they were created and endowed with their elementary properties by an all-wise and all-powerful Creator. This is Theism.

Another, that thought is the only reality, and that all the phenomena of the universe are thoughts or ideas of one universal, all-pervading Mind. This is Pantheism.

Or again, we may frankly acknowledge that the real essence and origin of things are "behind the veil," and not knowable or even conceivable by any faculties with which the human mind is endowed in its present state of existence. This is Agnosticism.

There is one other conception, of which we may certainly say that it is not true—that is Atheism. No one with the least knowledge of science can maintain that it can ever be demonstrated that everything in the universe exists of itself and never had a Creator.

But these speculations lead us into the misty regions where, like Milton's devils, "we find no end in wandering mazes lost." Let us return to the solid ground of fact, on which alone the human mind can stand firmly, and like Antæus gather fresh vigor every time it touches it for further efforts to enlarge the boundaries of knowledge and extend the domain of Cosmos over Chaos.

The transformation of energy which we have seen to exist in the case of mechanical work and heat, is not confined to those two cases only, but is a universal law applicable to all actions and arrangements of matter which involve motions of atoms, molecules, or masses, and therefore imply the existence of energy. In heat we have had an example of energy exerted in molecular motion and molecular separation. In chemical action we have energy exerted in the separation of atoms, severing them from old combinations and mutual attractions, and bringing them within the sphere of new ones. In electricity, and magnetism which is another form of electricity, we have energy of position which manifests itself in electrical separation, by which matter becomes charged with two opposite energies, positive and negative, which accumulate at separate poles, or on separate surfaces, with an amount of tension which may be reconverted into the original amount of energy of motion when the spark, passing between them, restores their electrical equilibrium. Of this we have an example in the ordinary electrical machine, where the original energy comes from the mechanical force which turns the handle, and is given back when the electric spark brings things back to their original state.

We have also energy of motion, when instead of electrical separation and tension we have a flow or current of electricity producing the effect of the electric spark in a slow, quiet, and continuous manner. Thus, in the voltaic battery, the free energy created by the difference of chemical action of an acid on plates of different metals, is transformed into a current which charges two poles with opposite electricities, and when the poles are brought together and the circuit is closed, flows through it in a continuous current. This current is an energetic agent which produces various effects. It deflects the magnetic needle, as is seen in the electric telegraph. It creates magnetism, as is seen when the poles of the battery are connected by a wire wrapped round and round a cylinder of soft iron, so as to make the current circulate at right angles to the axis formed by the cylinder. In fact, all magnetism may be consided as the summing up at the two opposite extremities or poles of an axis, of the effects of electric currents circulating round it; as, for instance, the earth is a great magnet because currents caused by the action of the sun circulate round it nearly parallel to the equator. Electric currents further show their energy by attracting and repelling one another, those flowing in the same direction attracting, and those in opposite directions repelling, the same effect showing itself in magnets, which are in substance collections of circular currents flowing from right to left or left to right according as they are positive or negative. Again, currents produce an effect by inducing currents in other bodies placed near them, very much as the vibrations of a tuning-fork induce vibrations and bring out a corresponding note from the strings of a piano or violin ready to sound it. When a coil of wire is connected with a battery and a current passes through it, if it is brought near to another isolated coil it induces a current in an opposite direction, which, when it recedes from it, is changed into a current in the same direction.

These principles are illustrated by the ordinary dynamo, by which the energy of mechanical work exerted in making magnets revolve in presence of currents, and by various devices accumulating electric energy, is made available either for doing other mechanical work, such as driving a wheel, or for doing molecular or atomic work by producing heat and light.

For another transformation of the energy of electric currents is into heat, light, or chemical action. If the two poles of a battery are connected by a thin platinum wire it will be heated to redness in a few seconds, the friction or resistance to the currant in passing through the limited section of the thin wire producing great heat. If the wire is thicker heat will equally be produced, but more slowly.

If the poles of the battery are made of carbon, or some substance the particles of which remain solid during intense heat, when they are brought nearly together the current will be completed by an arc of intensely brilliant light, and the carbon will slowly burn away. This is the electric light so commonly used when great illuminating power is wanted.

Again, the electric current may employ its energy in effecting chemical action. If the poles of a battery, instead of being brought together, are plunged into a vessel of water, decomposition will begin. Oxygen will rise in small bubbles at the positive pole, and hydrogen at the negative. If these two gases are collected together in the same vessel, and an electric current, in the intense and momentary form of a spark, passed through them, they will combine with explosion into the exact amount of water which was decomposed in their formation.

Everywhere, therefore, we find the same law of universal application. Energy, like matter, cannot be created or destroyed, but only transformed. It is therefore, in one sense, eternal. But there is another point of view from which this has to be regarded.

Mechanical work, as we have seen, can always be converted into heat, and heat can, under certain conditions, be reconverted into mechanical work; but not under all conditions. The heat must pass from something at a higher temperature into something at a lower. If the condenser of a steam-engine were always at the same temperature as the boiler, we should get no work out of it. It is easy to understand how this is the case if we figure to ourselves a river running down into a lake. If the stream is dammed up at two different levels, each dam, as long as there is water in it, will turn a mill-wheel. But if all the water runs down into the lake and, owing to a dry season, there is no fresh supply, the wheels will stop and we can get no more work done. So with heat, if it all runs down to one uniform temperature it can no longer be made available to do work. In the case of the river, fresh water is supplied at the higher levels, by the sun's energy raising it by evaporation from the seas to the clouds, from which it is deposited as rain or snow. But in the case of heat there is no such self-restoring process, and the tendency is always towards its dissipation; or in other words, towards a more uniform distribution of heat throughout all existing matter. The process is very slow; the original fund of high-temperature heat is enormous, and as long as matter goes on condensing fresh supplies of heat are, so to speak, squeezed out of it.

Still there is a limit to condensation, while there is no limit to the tendency of heat to diffuse itself from hotter to colder matter until all temperatures are equalized. The energy is not destroyed; it is still there in the same average amount of total heat, though no longer differentiated into greater and lesser heats, and therefore no longer available for life, motion, or any other form of transformation. This seems to be the case with the moon, which, being so much smaller, has sooner equalized its heat with surrounding space, and is apparently a burnt-out and dried-up cinder without air or water. And this, as far as we see, must be the ultimate fate of all planets, suns, and solar systems. Fortunately the process is extremely slow, for even our small earth has enjoyed air, water, sunshine, and all the present conditions necessary for life for the whole geological period, certainly from the Silurian epoch downwards, if not earlier, which cannot well be less than 100 millions of years, and may be much more. Still time, even if reckoned by hundreds of millions of years, is not eternity; and as, looking through the telescope at nebulæ which appear to be condensing about central nuclei, we can dimly discern a beginning, so, looking at the moon and reasoning from established principles as to the dissipation of heat, we can dimly discern an end. What we really can see is that throughout the whole of this enormous range of space and time law prevails; that, given the original atoms and energies with their original qualities, everything else follows in a regular and inevitable succession; and that the whole material universe is a clock, so perfectly constructed from the beginning as to require no outside interference during the time it has to run to keep it going with absolute correctness.

CHAPTER IV.

LIFE.

THE universe is divided into two worlds—the inorganic, or world of dead matter; and the organic, or world of life. What is life? In its essence it is a state of matter in which the particles are in a continued state of flux, and the individual existence depends, not on the same particles remaining in the same definite shape, but on the permanence of a definite mould or form through which fresh particles are continually entering, forming new combinations and passing away. It may assist in forming a conception of this if we imagine ourselves to be looking at a mountain the top of which is enveloped in a driving mist. The mountain is dead matter, the particles of which continue fixed in the rocks. But the cloud form which envelops it is a mould into which fresh particles of vapor are continually entering and becoming visible on the windward side, and passing away and disappearing to leeward. If we add to this the conception that the particles do not, as in the case of the cloud, simply enter in and pass away without change, but are digested, that is, undergo chemical changes by which they are partly assimilated and worked up into component parts of the mould, and partly thrown off in new combinations, we shall arrive at something which is not far off the ultimate idea of what constitutes living matter, in its simplest form of the protoplasm, or speck of jelly-like substance, which is shown to be the primitive basis or raw material of all the more complex forms both of vegetable and animal life. Digestion, therefore, is the primary attribute. A crystal grows from *without*, by taking on fresh particles and building them up in regular layers according to fixed laws, just as the pyramids of Egypt were built up by laying layer upon layer of squared stones upon surfaces formed of regular figures, and inclined to each other at determinate angles.

The living plant or animal grows from within by taking supplies of fresh matter into its inner laboratory, where it is worked up into a variety of complex products needed for the existence and reproduction of life. After supplying these, the residue is given back in various forms to the inorganic world, and the final residue of all is given back by death, which is the ultimate end of all life

The simplest form of life, in which it first emerges from the inorganic into the organic world, consists of protoplasm, or, as it has been called, the physical basis of life. Protoplasm is a colorless semi-fluid or jelly-like substance, which consists of albuminoid matter, or in other words, of a heterogeneous carbon-compound of very complex chemical composition. It exists in every living cell, and performs the functions of nutrition and reproduction, as well as of sensation and motion. In its simplest form, that of the microscopic monera or protista, the lowest of living beings, we find a homogeneous structureless piece of protoplasm, without any differentiation of parts. The monera are simple living globules of jelly, without even a nucleus or any sort of organ, and yet they perform all the essential functions of life without any different parts being told off for particular functions. Every particle or molecule is of the same chemical composition and a fac-simile of the whole body, as in the case of a crystal. They are, therefore, the first step from the inorganic into the organic world, and if spontaneous generation takes place anywhere, it is in the passage of the chemical elements from the simple and stable combinations of the former into the complex and plastic combinations of the latter.

These monera are found principally in the sea and in great masses at the bottom of deep oceans, where they form a sort of living slime first described by Huxley in 1868, and called Bathybius.

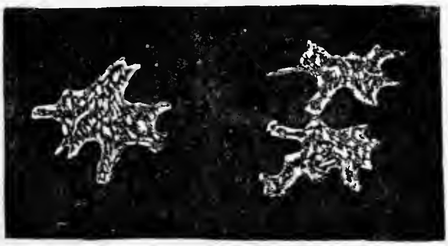
The next step upwards is to the cell in which the protoplasm is enclosed in a skin or membrane of modified protoplasm, and a nucleus, or denser spot, is developed in the enclosed mass. This is the primary element from which all the more complicated forms of life are built up. Each cell seems to have an independent life of its own, and a faculty of reproduction by splitting into fresh cells similar to itself, which multiply in geometrical progression, assimilating the elements of their substance from the inorganic world so rapidly as to provide the requisite raw material for higher structures.

The first organized living forms are extremely minute, and can only be recognized by powerful microscopes. A filtered infusion of hay, allowed to stand for two days, will swarm with living things, a number of which do not exceed $\frac{1}{40,000}$ of an inch in diameter. Minute as these animalcula are, they are thoroughly alive. They dart about and digest; the smallest speck of jelly-like substance shoots out branches or processes to seize food, and if these come in collision with other substances they withdraw them. They exist in countless myriads, and perform a very important part in the economy of nature. They are the scavengers of the universe, and remove the remains of living matter after death, which would otherwise accumulate until they choked up the earth. This they do by the process of putrefaction, which is due mainly to the multiplication of little rod-like creatures known as bacteria, which work up the once living, now dead, matter into fresh elements, again fitted to play their part in the inorganic and organic worlds.

One of the simplest of these forms is the amœba, which is nothing but a naked little lump of cell-matter, or plasma, containing a nucleus; and yet this little speck of jelly moves freely, it shoots out tongues or processes and gradually draws itself up to them with a sort of wave-like motion; it eats and grows, and in growing reproduces itself by contracting in the middle and splitting up into two independent amœbæ.

The germs of these various animalcula swarm in the air, and carry seeds of infection everywhere where they find a soil fitted to receive them; and thus assist the survival of the fittest in the struggle of life, by eliminating weak and unhealthy individuals and species. Thus when the potato, the vine, or the silk-worm has had its constitution enfeebled by prolonged artificial culture, there are germs always ready to revenge the violation of natural laws, and bring the survivors back to a more healthy condition. In like manner the germs of cholera, typhoid, and scarlet fever, enforce the observance of sanitary principles.

In this simple form the lowest forms of life are not yet sufficiently differentiated to enable us to distinguish clearly between animal and



AMŒBA. AMŒBA dividing into two.

vegetable, and they have been called by some naturalists Protista, while others designate them as Protozoa or Protophyta, according as they show more resemblance to one or the other form of life. But it is often so doubtful that in looking at the same organism through a microscope, Huxley was inclined to consider it as a plant, while Tyndall exclaimed that he could as soon believe that a sheep was a vegetable.

In the next stage upwards, however, life subdivides itself into two great kingdoms, that of the vegetable and of the animal world. Alike in their general definition as contrasted with inorganic matter, and in their common origin from an embryo cell, which divides and subdivides until cell-aggregates are formed, from which the living form is built up by a process of evolution, the plant differs from the animal in this: that the former feeds directly on inorganic matter, while the latter can only feed on it indirectly, after it has been manufactured by the plant into vegetable substance.

This is universally true, for if we dine on beef, we dine practically on the grass which the ox ate; that is, on the carbon, oxygen, hydrogen, and other simple elements which the grass, under the stimulus of light and sunshine, manufactured into complex compounds; and which the ox again, by a second process, manufactured from these compounds into others still more complex, and more easily assimilated by us in the process of digestion. But in no case can we dine, as the plant does, on the simple elements, and thrive on a diet of air and water, with a small admixture of nitrate of ammonia, and of phosphates, sulphates and chlorides, of a few primitive metals. Vegetable life, therefore, is the producer, and animal life the consumer, of the organic world.

Practically the plant derives most of its substance from the carbonic acid gas in the atmosphere, which green leaves under the stimulus of light and heat have the faculty of decomposing, and abstract the carbon giving out the oxygen; while the animal, by a reverse process, burns up the compounds manufactured by the plant, principally out of this carbon, by the oxygen obtained from the air by the process of respiration, exhaling the surplus carbon in the form of carbonic acid gas.

The balancing effect of these two processes may be seen in any aquarium, where animals and vegetables live together in water which is kept pure, while it would become stagnant and poisonous in a few hours, if one of the two forms of life were removed. All that the animal requires therefore for its existence, materials with which to build up its frame and supply waste; heat with which to maintain its circulating fluids and other substances at a proper temperature; motive power or energy to enable it to move, feel, and in the case of man to think; are all proceeds of the slow combustion of materials derived from the vegetable world in the oxygen breathed from the air, just as the work done by a steam-engine is the product of a similar combustion, or chemical combination of the oxygen of the air with the coal shovelled into the fire-box. These distinctions, however, between animals and vegetables are not quite absolute, for, even in the more highly-organized forms of life, there is a border-land where some plants seem to perform the functions of animals, as in those which catch and consume flies and eat and digest pieces of raw meat.

Those who wish to pursue this interesting subject further will do well to read the Chapter on Living Matter in Huxley's "Physiography," where they will find it more fully explained, with the inimitable clearness which characterizes all the writings of an author who is at the same time one of the first scientific authorities and one of the greatest masters of English prose. But my present object is not to write a scientific treatise, but shortly to sum up the ascertained results of modern science, with a view to their bearings on modern thought; and from this point of view the immediate question is, how far law, which has been shown to prevail universally throughout space, time, and inorganic matter, can be shown to prevail equally throughout the world of life.

Up to a certain point this admits of positive proof. It is as certain that all individual life, from the most elementary protoplasm up to the highest organism Man, originates in a minute or embryo cell, as it is that oxygen and hydrogen combined in certain proportions make water. But if we try to go back one step further, behind the cell, we are stopped. In the inorganic world we can reason our way beyond the microscopic matter to the molecule, and from the molecule to the atom, and are only arrested when we come to the ultimate form of matter, and of energy, out of which the universe is built up. But, in the case of life, we are stopped two steps short of this, and cannot tell how the cell containing the germ of life is built up out of the simpler elements.

Many attempts have been made to bridge over this gulf, and show how life may originate in chemical compounds, but hitherto without success. Experiments have been made which, for a time, seemed to show that spontaneous generation was a scientific fact, *i.e.*, that the lowest forms of life, such as bacteria and amœba, really did originate in infusions containing no germs of life; but they have been met by counter experiments confirming Harvey's *dictum*, "Omne animal ex ovo," or all life proceeds from antecedent germs of life, and the verdict of the best authorities, such as Pasteur, Tyndall, and Huxley is, that spontaneous generation has been "defeated along the whole line." This verdict is perhaps too unqualified, for it certainly appears that, on the assumption with which both sides started, that all organic life was destroyed by exposure to a heat of 212°, or the boiling-point of water, the advocates of spontaneous generation had the best of it, as low forms of life did appear in infusions which had been exposed to this heat, and then hermetically sealed, so as to prevent any germs from entering. But it was replied that, as a hard pea takes more boiling than a soft one, it might very well be that heat sufficient to destroy life in any moist organism of sufficient size to be seen by the microscope, might not destroy the germinating power of ultra-microscopic germs in a very dry state. And this position seems to have been confirmed by various experiments, showing that such ultra-microscopic germs really do exist, and are given forth in the last life stage of the bacteria which cause putrefaction; and that if they are absent or destroyed by repeated applications of heat, infusions will keep sweet for ever in optically pure air.

Above all, the germ theory has received confirmation from the brilliant practical results to which it has led in the hands of Pasteur, enabling him to detect, and to a great extent eradicate, the causes which had led to the oidium of the vine and the pebrine of the silk-worm, thereby saving losses of millions to the industries of France. The germ theory has also led to important results in medical science, and is pointing towards the possibility of combating the most fatal diseases by processes analogous to that by which vaccination has almost freed the human race from the scourge of small-pox.

On the whole, therefore, we must be content to accept a verdict of "Not proven" in the case of spontaneous generation, and admit that as regards the first origin of life, science fails us, and there is at present no known law that will account for it.

Should spontaneous generation ever be proved to be a fact, it will doubtless be in creating living protoplasm from inorganic elements at its earliest stage, before it has been differentiated even into the primitive form of a nucleated cell or that of an amœba. This is what the doctrine of evolution would lead us to expect, for it would be in contradiction to it to suppose that the starting-point could be interpolated at any stage subsequent to the lowest. It may be also that this step could only be made under conditions of heat, pressure, and otherwise, which existed in the earlier stage of the earth's existence, but have long since passed away.

This, however, is only a small part of the difficulty we have to encounter in reducing life to law.

These primeval embyro cells, like as they are in appearance, contain within them the germs of an almost infinite diversity of evolutions, each running its separate course distinct from the others. The world of life is not one and uniform, but consists of a vast variety of different species, from the speck of protoplasm up to the forest tree, and from the humble amœba up to man, each one, at any rate within long intervals of time, breeding true and keeping to its own separate and peculiar path along the line of evolution.

The first germ, or nucleated cell, of a bacteria develops into other bacteria and nothing else, that of a coral into corals, of an oak into oaks, of an elephant into elephants, of a man into man. In the latter case we can trace the embryo in its various stages of growth through forms having a certain analogy to those of the fish, the reptile, and the lower mammals, until it finally takes that of the human infant. But we have no experience of a fish, a frog, or a dog, being ever born of human parents, or of any of the lower animals ever producing anything resembling a man.

How can this be explained? Naturally the first attempt at explanation was by miracle. At a time when everything was explained by miracle, when all unusual occurrences were attributed to supernatural agency, and men lived in an atmosphere of providential interferences, witchcraft, magic, and all sorts of divine and diabolic agencies, nothing seemed easier than to say the beasts of the field, the birds of the air, and the fishes of the sea are all distinct after their kind, because God created them so.

But as the supernatural faded away and disappeared in other departments where it had so long reigned supreme, and science began to classify, arrange, and accumulate facts as they really are, it became more and more difficult, or rather impossible, to accept this simple explanation. The very first step destroyed the validity of all the traditional myths which described the origin of life from one simultaneous act of creation at a single centre. The earth is divided into separate zoölogical provinces, each with its own peculiar animal and vegetable world. The kangaroo, for instance, is found in Australia and there only. By no possibility could the aboriginal kangaroo have jumped at one bound from Mount Ararat to Australia, leaving no trace of his passage in any intermediate district. This isolation of life in separate provinces applies so rigidly, that we may sum it up by saying generally that there are no forms of life common to two provinces unless where migration is possible, or has been possible in past geological periods.

In islands at a distance from continents, we find common forms of marine life, for the sea affords a means of communication; and often common forms of bird, insect, and vegetable life, where they may have been wafted by the winds; but forms which neither in the adult or germ state could swim or fly, or be transported by something which did swim or fly, are invariably wanting. New Zealand affords a most conspicuous instance of this. Here is a large country with a soil and climate exceptionally well adapted to support a large amount of animal life of the higher orders, and yet it had absolutely no land animals before they were introduced by man. If special creations took place to replenish the earth as soon as any portion of its surface becomes fit to sustain it, why were there no animals in New Zealand? Or, in the Andaman Islands, in the Gulf of Bengal, which are as large as Ireland, covered with luxuriant vegetation, and within 300 miles of the coast of Asia, where similar jungles swarm with elephants, tigers, deer, and all the varied forms of mammalian life, there are no mammalia except a pigmy black savage and a pigmy black pig, the latter probably introduced by man.

The sharpness of the division between zoölogical provinces is well illustrated by that drawn by the Straits of Lombok, where a channel, not twenty miles wide, separates the fauna of Asia and Australia so completely that there are no species of land animals, and only a few of birds and insects, common to the two sides of a channel not so wide as the Straits of Dover.

There is no possibility of accounting for this, except by supposing that the deep water fissure of the Strait of Lombok has existed from remote geological periods, and barred the migration southwards of those Asiatic animals, which, as long as they found dry land, migrated northwards and westwards till they were stopped by the Polar and Atlantic Oceans. This difficulty of requiring special creations for separate provinces is enormously enhanced if we look beyond the existing condition of things, and trace back the geological record. We must suppose separate creations for all the separate provinces of the separate successive formations from the Silurian upward. And the more we investigate the conditions of life either under existing circumstances or in those of past geological epochs, the more enormously are we driven to multiply the number of separate creations which would be necessary to account for the diversity of species. We find life shading off into an indefinite variety of almost imperceptible gradations from the highest organism, man, to the lowest, or speck of protoplasm, and we can draw no hard and fast line and say, up to this point life originated in law, and beyond it we must have recourse to miracle. Either all life or none is a product of evolution acting by defined law, and the affirmation of law is the negation of miracle.

Every day brings us an account of some new discovery bringing forms of life nearer together and bridging over intervals thought to be impassable. The discovery of plants living on insects, and which devour and digest pieces of raw meat, has added to the difficulty which has been long felt, in the humbler forms of life, of drawing any clear line of demarcation between the animal and vegetable worlds.

Microscopic research brings to light fresh facts confounding our fixed ideas as to the permanence of particular modes of reproducing life, and showing that the same organism may run through various metamorphoses in the course of its life-cycle, during some of which it may be sexual and in others asexual, *i.e.*, it may reproduce itself alternately by the co-operation of two beings of opposite sex, and by fissure or budding from one being only which is of no sex.

These, and a multitude of other similar facts, complicate enormously the problems of life and its developments, whether we attempt to solve it by calling in aid a perpetual series of innumerable miraculous interpositions, or by appealing to ordinary known laws of Nature.

Is the latter solution possible, and can the organic world be reduced, as the inorganic world has been with all its mysteries and infinities of space, time, and matter, from chaos into cosmos, and shown to depend on permanent and harmonious laws? Is the world of life, like that of matter, a clock, so perfectly constructed from the first that it goes without winding up or regulating? or is it a clock which would never have started going, or having started would soon cease to go if the hand of the watchmaker were not constantly interfering with it? This is the question which the celebrated Darwinian theory attempts to answer, of which I now proceed to give a short general outline.

The varieties among domestic animals are obvious to every one. The race-horse is a very different creature from the dray-horse; the short-horned ox from the Guernsey cow; the greyhound from the Skye terrier. How has this come to pass? Evidently by man's intervention, causing long-continued selection in breeding for certain objects. The English race-horse is the product of mating animals distinguished for speed for some fifteen or twenty generations. The greyhound is a similar dog-product by breeding for a longer period with the same object; as the Skye terrier is of selection in order to get a dog which can follow a fox into a cairn of rocks and fight him when he gets there. In all these cases it is evident that the final result was not attained at once, but by taking advantage of small accidental variations and accumulating them from one generation to another by the principle of heredity, which make offspring reproduce the qualities of their parents.

The most precise and scientific experiments on this power of integrating, or summing up, a progressive series of differentials, or minute differences, between successive generations, are those conducted by Darwin on pigeons. He has shown conclusively that all the races of domestic pigeons, of which there are two or three hundred, are derived from one common ancestor, the wild or blue rock pigeon, and that the pigeon-fancier can always obtain fresh varieties in a few generations by careful interbreeding. Of the existing varieties many now differ widely from one another, both in size, appearance, and even in anatomical structure, so that if they were now discovered for the first time in a fossil state or in a new country, they would assuredly be classed by naturalists as separate species.

This is the work of man; is there anything similar to it going on in Nature? Yes, says Darwin, there is a tendency in all life, and especially in the lower forms of life, to reproduce itself vastly quicker than the supply of food and the existence of other life can allow, and the balance of existence is only preserved by the wholesale waste of individuals in what may be called the "struggle for life." In this struggle, which goes on incessantly and on the largest scale, the slightest advantage must tell in the long run, and on the average, in selecting the few who are to survive, and such slight advantages must tend to accumulate from one generation to another under the law of heredity. The cumulative power of selection exercised by man in the breeding of races is therefore necessarily exercised in Nature by the struggle for life, and in the course of time, by the cumulation of advantages originally slight, small and fluctuating variations are hardened into large and permanent ones, and new species are formed.

Darwin illustrates this principle of the "struggle for life" with a vast variety of instances, showing how the balance of animal and vegetable life may be preserved or destroyed in the most unexpected manner. For instance, the fertilization of red clover is effected by humble-bees, and depends on their number; the number of bees in a given district depends mainly on the number of field-mice which destroy their combs and nests; the number of mice depends on the number of cats; and thus the presence or absence of a carnivorous animal may decide the question whether a particular sort of flora shall prevail over others or be extirpated.

The countless profusion with which any one species, unchecked by its natural foes, may multiply in a given district, is illustrated by the potato disease, which in a few days invades whole countries; and by the rabbit plague in Australia and New Zealand, where, in less than twenty years, the descendants of a few imported pairs have rendered whole provinces useless for sheep pasture, and stoats are now being imported to restore the balance of life. The tendency in species to produce varieties which by selection may become exaggerated and fixed, is illustrated by the case of the Ancon herd of sheep. A ram lamb was born in Massachusetts in 1791, which had short crooked legs and a long back like a turnspit dog. Being unable to jump over fences like the ordinary sheep, it was thought to possess certain advantages to the farmer, and the breed was established by artificial selection in pairing this ram with its descendants who possessed the same peculiarities. The introduction of the Merino superseded the Ancon by giving a tame sheep not given to jump fences, with a better fleece, and so the breed was not continued, but it is certain that it might have been established as a permanent variety differing from the ordinary sheep as much as the turnspit or Skye terrier differs from the ordinary dog. The tendency of Nature to variation is apparent in the fact that of the many hundred millions of human beings living on the earth, no two are precisely alike, and varieties often appear, as in giants and dwarfs, six-fingered or toed children, hairy and other families, which might doubtless be fixed and perpetuated by artificial or natural selection, until they became strongly marked and permanent.

It is evident that if the theory of development is true it excludes the old theory of design, or rather, it thrusts it back in the organic, as it has been thrust back in the inorganic world, to the first atoms or origins which were made so perfect as to carry within them all subsequent phenomena by necessary evolution. Design and development lead to the same result, that of producing organs adapted for the work they have to do, but they lead to it in totally different ways. Development works from the less to the more perfect, and from the simpler to the more complicated, by incessant changes, small in themselves but constantly accumulating in the required direction. Design supposes that organisms were created specially on a predetermined plan, very much as the sewing-machine or self-binding reaper were constructed by their inventors.

Until quite recently all adaptations of means to ends were considered as evidences of design. A series of treatises was published some thirty years ago, for prizes left by a late Duke of Bridgewater, to illustrate this theme, among which one by Sir Charles Bell on the Hand attracted a good deal of attention. It was shown what an admirable machine the human hand is for the various purposes for which it is used, and the inference was drawn that it must have been created so by a designer who adapted means to ends in much the same way as is done by a human inventor. But more complete knowledge has dispelled this idea, and shown that the design, if there be any, must be placed very much farther back, and is in fact involved in the primitive germ from which all vertebrate life certainly, and probably all life, animal or vegetable, have been slowly developed.

The human hand is in effect the last stage of a development of the vertebrate type, or type of life in which a series of jointed vertebræ form a backbone, which protects a spinal cord containing the nervous centres, gives points of attachment for the muscles, and forms an axis of support for the looser tissues. Certain of these vertebræ throw out bony spines or rays; at first, by a sort of simple process of vegetable growth, which formed the fins of fishes; then some of these rays dropped off and others coalesced into more complex forms, which made the rudimentary limbs of reptiles; and finally, the continued process of development fashioned them into the more perfect limbs of birds and mammals. In this last stage a vast variety of combinations was developed. Sometimes the bones of the extremities spread out, so as to form long fingers supporting the feathered wings of birds and the membraneous wings of bats; sometimes they coalesced into the solid limbs supporting the bodies of large animals, as in the case of the horse; and finally, at the end of the series, they formed that marvellous instrument, the hand, as it appears in the allied genera of monkeys, apes, and man.

Any theory of secondary design and special miraculous creation must evidently account for all the intermediate forms as well as for the final result. We must suppose not one but many thousands of special creations, at a vast variety of places and over a vast extent of time; we must take into account not the successes only, but the failures, where organs appear in a rudimentary form which are perfectly useless, or in some cases even injurious, to the creature in which they are found. For instance, in the case of the so-called wingless birds, like the dodo of the Mauritius, and the apteryx of New Zealand, which are found in oceanic islands, evolution accounts readily for the atrophy or want of development of organs which were not wanted where the birds had no natural enemies and found their food on the ground; but why should they have been created with rudimentary wings, useless while they remained isolated, and insufficient to prevent their extermination as soon as man, or any other natural enemy, reached the islands where they had lived secure?

If we are to adopt the theory of design and special creation, we must be prepared to take Burns' poetical fancy as a scientific truth, and believe that Nature had to try its "prentice hand," and grope its way through repeated trials and failures from the less to the more perfect. Again, the theory of special creation must account not only for the higher organs and forms of life, but for the lower forms also. Are the bacteria, amœbæ, and other forms of life which the microscope shows in a drop of water all instances of a miraculous creation? And still more hard to believe, is this the origin of the whole parasitic world of life which is attached to and infests each its own peculiar form of higher life? Is the human tape-worm a product of design, or that wonderful parasite the trichinia, which oscillates between man and the pig, being capable of being born only in the muscles of the one, and of living only in the intestines of the other?

These are the sort of difficulties which have led the scientific world, I may say universally, to abandon the idea of separate special creations, and to substitute for it that which has been proved to be true of the whole inorganic world of stars, suns, planets, and all forms of matter; the idea of an original creation (whatever creation may mean and behind which we cannot go) of ultimate atoms or germs, so perfect that they carried within them all the phenomena of the universe by a necessary process of evolution.

This is the idea to which the Darwinian theory leads up, by showing natural causes in operation which must inevitably tend to cause and to accumulate slight varieties, until they become large in amount and permanent, thus developing new races within old species, new species within old families, new families within old types, and new and complex types from old and simple ones.

The theory is up to a certain point undoubtedly true, and beyond that point in the highest degree probable, but scientific caution obliges us to add that it is still to a considerable extent a "theory," and not a "law." That is, it is not like the law of gravity, a demonstrated certainty throughout the whole universe, but a provisional law which accounts for a great number of undoubted facts, and supplies a framework into which all other similar facts, as at present ascertained, appear to fit with a probability not approached by any other theory, and which is enhanced by every fresh discovery made, and by the analogy of what we know to be the laws which regulate the whole inorganic world.

To enable us to talk of the "Darwinian law," and not of the "Darwinian theory," we require two demonstrations:

1. That living matter really can originate from inorganic matter.
2. That new species really can be formed from previously existing species.

As regards the first, we have seen that the efforts of science have hitherto failed to produce an instance of spontaneous generation, and all we can say is that it is probable that such instances have occurred in earlier ages of our planet, under conditions of light, heat, chemical action, and electricity, different from anything we can now reproduce in our laboratories. This, however, falls short of demonstration, and for the present we must be content to leave the orgin of life as one of the mysteries not yet brought within the domain of law.

As regards the second point, we are further advanced towards the possibility of proof. But here also we are met by two difficulties. If we appeal to historical evidence, we are met by the fact that a much greater time than is embraced by any historical record is almost necessarily required for the dying out of any old species and introduction of any new one, by natural selection. And if we appeal to fossil remains we are met by the imperfection of the geological record. As to this, it must be remembered that only a very small portion of the earth's surface has been explored, and of this a very small portion consists of ancient land surfaces or fresh water formations, where alone we can expect to meet with traces of the higher forms of animal life. And even these have been so imperfectly explored, that where we now meet with thousands and tens of thousands of undoubted human remains lying almost under our feet, it is only within the last thirty years that their existence has ever been suspected. Cuvier, the greatest authority of the last generation, laid it down as an incontrovertible fact that neither men nor monkeys had existed in the fossil state, or in anything more ancient than the most superficial and recent deposits. We have now at least twenty specimens of fossil monkeys from one locality alone of the Miocene period, that of Pikermi, near Athens, and many thousands of human remains, at least into the Quaternary period and contemporary with extinct animals, if not earlier. We must be content, therefore, with approximate solutions pointing up to but not absolutely demonstrating the truth.

What is a species? Speaking generally it is an assemblage of individuals who maintain a separate family type by breeding freely among themselves, and refusing to breed with other species. There can be no doubt that this represents what, at the first view and for a limited range of time, is in accordance with actual facts. The animal and vegetable worlds are practically mapped out into distinct species, and do not present the mass of confusion which would result from indiscriminate cross-breeding. It is clear also that this state of things has lasted for a considerable time, for the paintings on Egyptian tombs and monuments carry us back more than 4,000 years, and show us the most strongly marked varieties of the human race, such as the

Semitic, the Egyptian, and the Negro, existing just as they do at the present day. They show us also such extreme varieties of the dog species as the greyhound and the turnspit, then in existence; and the skeletons of animals such as the ox, cat, and crocodile, which have been preserved as mummies, show no appreciable difference from those of their modern descendants.

When we come to look closely, however, into the matter, our faith in this absolute rule of the entire independence of species is greatly modified. In the lower grades of life we see everywhere species shading off into one another by insensible gradations, and every extension of our knowledge, both of the existing animal, vegetable, and microscopic worlds, and of those of past geological periods, multiplies instances of intermediate forms, differing from one another far less than do many of the individual varieties of recognized species. In the case of sponges, for instance, the latest conclusion of scientific research is this: that if you rely on minute distinctions as constituting distinct species, there are at least 300 species of one family of sponges, while if you disregard slight differences, which graduate into one another, and are found partly in one and partly in another variety, you must designate them all as forming only one species. Even in higher grades, as species are multiplied, it becomes more and more difficult to say where one ends and the other begins. Take the familiar instance of the grouse and ptarmigan. The red grouse is believed to be peculiar to the British Islands, while the ptarmigan is a very widely spread inhabitant of Arctic regions and high mountains. Which is more probable—that the grouse was specially created in the British Islands, apparently for the final cause of bringing sessions of Parliament to wind up business in August, or that, as the rigor of the Glacial period abated, and heather began to grow, certain ptarmigan by degrees modified their habits and took to feeding on heather tops instead of lichens, and by so doing gradually became larger birds and assumed the color best adapted for protection in their new habitation? In point of fact, grouse showing traces of this descent in smaller size and much whiter plumage are still to be met with. It would be easy to multiply instances, but this consideration seems conclusive.

If we reject the Darwinian theory and adopt that of independent species descended from a specially created ancestor or pair of ancestors, we are driven by each discovery of intermediate or slightly modified forms, into the assumption of more and more special acts of creation, until the number breaks down under its own weight, and belief becomes impossible.

For instance, in the Madeira Islands alone, 134 species of air-breathing land-snails have been discovered by naturalists, of which twenty-one only are found in Africa or Europe, and 113 are peculiar to this small group of islands, where they are mostly confined to narrow districts and single valleys. Are we to suppose that each of these 113 species was separately created? Is it not almost certain that they are the modified descendents of the twenty-one species which had found their way there in a former geological period, when Madeira was united to Africa and Spain?

There remains only the argument from the fertility of species *inter se*, and their refusal to breed with other species. This also, when closely examined, appears to be a *primâ facie* deduction, rather than an absolute law. Different species do, in fact, often breed together, as is seen in the familiar instance of the horse and ass. It is true that in this case the mule is sterile and no new race is established. But this rule is not universal, and quite recently one new hybrid race, that of the leporine, or hare-rabbit, has been created, which is perfectly fertile. The progeny of dog and wolf has also been proved to be perfectly fertile during the four generations for which the experiment was continued. In the case of cultivated plants and domestic animals, there can be little doubt that new races, which breed true and are perfectly fertile, have been created within recent times from distinct wild species. The Esquimaux dog is so like the Arctic wolf that there can be little doubt he is either a direct descendant, or that both are descendants from a common stock. The same is true of the jackal and some breeds of dogs in the East and Africa, and other races of dogs are closely akin to foxes. But all dogs breed freely together, and can with difficulty be mated with the wild species which they so closely resemble. The modern Swiss cattle are pronounced by Rutimeyer to show undoubted marks of descent from three distinct species of fossil oxen, the *Bos primigenius*, *Bos longifrons*, and *Bos frontosus*.

There is now in the Zoölogical Gardens in Regent's Park a hybrid cow, whose sire was an American bison and its mother a hybrid between a zebu and a gayal. This animal is perfectly fertile, and has bred again to the bison; but what is singular is, that this hybrid resembles much more an ordinary domestic English cow than it does any of its progenitors. It is totally unlike the bison, both in appearance and disposition, and, except in having a projecting ridge over the withers, it might be mistaken for a coarse, bony, common cow. If a hybrid bull had been born of the same type, and mated with this hybrid cow, there is little doubt that a new race might have been established, extremely different from its ancestors.

In fact, nearly all the domesticated animals have the essential characters of new races. We cannot point to wild progenitors existing in any part of the world from which they are descended, and when they run wild they do not revert to any common ancestral form.

In the vegetable world instances of fertile hybrids are still more abundant, and the introduction and establishment of new varieties is a matter of every-day occurrence.

Now, whatever artificial selection can do in a short time, natural selection can certainly do in a longer time, and nothing short of absolute proof of the impossibility of species coming into existence by natural laws should induce us to fall back on the supernatural theory, with all its enormous difficulties of an innumerable multitude of special creations, most of them obviously imperfect and tentative—or rather, useless and senseless on any supposition except that of a necessary and progressive evolution. In fact, if it were not for its bearing on the nature and origin of man, few would be found to maintain the theory of miraculous creations, or to doubt that the world of life is regulated by fixed laws as well as the world of matter. But whatever touches man touches us closely, and brings into play a host of cherished aspirations and beliefs, which are too powerful to be displaced readily by calm, scientific reasoning. Shall man, who, we are told, was created in God's image and only "a little lower than the angels," be degraded into relationship with the brutes, and shown to be only the last development of an animal type which, in the case of apes and monkeys, approaches singularly near to him in physical structure? Are the saints and heroes whom we revere, and the beautiful women whom we admire, descended, not from an all-glorious Adam and all-lovely Eve, as portrayed in Milton's "Paradise Lost," but from Palæolithic savages, more rude and bestial than the lowest tribe of Bushmen or Australians? Is the account of man's creation and fall in the Hebrew Scriptures as pure a myth as that of Noah's ark, or of Deucalion and Pyrrha?

The only answer to these questions is that truth is truth, and fact is fact, and that it is always better to act and to believe in conformity with truth and fact, than to indulge in illusions. There are many things in Nature which jar on our feelings and seem harsh and disagreeable, but yet are hard facts, which we have to recognize and make the best of. Childhood does not pass into manhood without exchanging much that is innocent and attractive for much that is stern and prosaic. Death, with its prodigal waste of immature life, its sudden extinction of mature life in the plenitude of its powers, its heart-rending separations from loved objects, is a most disagreeable fact. But it would not improve matters to keep grown-up lads in nurseries for fear of their meeting with accidents, or becoming hardened by contact with the world. Progress, not happiness, is the law of the world; and to improve himself and others by constant struggles upwards is the true destiny of man.

In working out this destiny the fearless recognition of truth is essential. Facts are the spokes of the ladder by which we climb from earth to heaven, and any individual, nation, or religion, which, from laziness or prejudice, refuses to recognize fresh facts, has ceased to climb and will end by falling asleep and dropping to a lower level.

"Prove everything, hold fast that which is true," is the maxim which has raised mankind from savagery to civilization, and which we must be prepared to act upon at all hazards and at all sacrifices, if we wish to retain that civilization unimpaired and to extend it further.

CHAPTER V.

ANTIQUITY OF MAN.

GREAT as the effect has been of the wonderful discoveries of modern science of which I have attempted to give a general view in the preceding chapters, there remains one which has had the greatest effect of all in changing the whole current of moden thought, viz., the discovery of the enormous antiquity of man upon earth, and his slow progress upwards from the rudest savagery to intelligence, morality, and civilization. It is needless to point out in what flagrant and direct opposition this stands to the theory that man is of recent miraculous creation, and that he was originally endowed with a glorious nature and high faculties, which were partially forfeited by an act of disobedience. It is important, therefore, to understand clearly the evidence upon which a conclusion rests, so startling and unexpected as that which traces the origin of man back into the remote periods of geological time.

It had been long known that a stone period preceded the use of metals. Flint arrow-heads, stone axes, knives, and chisels, rude pottery, and other human remains lie scattered almost everywhere, on or near the existing surface, and are found in the sepulchral mounds and monuments which abound in all countries until they are destroyed by the progress of agriculture. These are certainly ancient, for their origin was so completely forgotten that the stone hatchets or celts (from the Latin *celtis*, or chisel) were universally believed to be thunderbolts which had fallen from heaven. But there was no proof that they were very ancient, they were always found at or near the present surface, and if animal remains were associated with them, they were those of the dog, ox, sheep, red deer, and other wild and domestic species now found in the same district. Historical record was not supposed to extend beyond the 4,000 or 5,000 years assigned to it by Bible chronology, and it was thought that this might be sufficient to account for all the changes which had occurred since man first became an inhabitant of the earth. Above all, the negative evidence was relied on, that geologists had explored far and wide, and although they had found fossil remains which enabled them to restore the characteristic fauna of so many different formations, they had found no trace of man or his works anywhere below the present surface. This seemed so conclusive that Cuvier, the greatest authority of the day, pronounced an emphatic verdict that man had not existed contemporaneously with any of the extinct animals, and probably not for more than 5,000 or 6,000 years. Here, then, appeared to be an edifice based on scientific fact, in which geologists and theologians could dwell together comfortably, and the weight of their united authority was sufficient to silence all objections, and ignore or explain away the instances which occasionally cropped up, of human remains found in situations implying greater antiquity.

Suddenly, I may almost say in a single day, this edifice collapsed like a house of cards, and the fact became apparent that the duration of human life on the earth must be measured by periods of tens, if not of hundreds of thousands of years.

It happened thus: A retired French physician, Monsieur Boucher de Perthes, residing at Abbeville, in the valley of the Somme, had a hobby for antiquarianism as decided as that of Monkbarns himself. Abbeville afforded him a capital collecting-ground for the indulgence of his tastes, as the sluggish Somme flows through a series of peat mosses, which are extensively worked for fuel, and afford many remains of the Gallo-Roman and pre-Roman or Celtic period. Higher up, on the slopes of the low hills which bound the wide valley, are numerous beds of gravel, sand, and brick-earth, which are also extensively worked for road and building materials. In these pits remains of the mammoth, rhinoceros, and other extinct animals are frequently found, and the workmen had noticed occasionally certain curiously-shaped flints, to which they gave the name of "langues du chat," or cats' tongues. Some of these were taken to Monsieur Boucher de Perthes as curiosities for his museum, and he at once recognized them as showing marks of human workmanship. This put him on the trace, and in the year 1841 he himself discovered, *in situ*, in a seam of sand containing remains of the mammoth, a flint rudely but unmistakably fashioned by human hands into a cutting instrument. During the next few years a large quantity of gravel was removed to form the Champ de Mars at Abbeville, and many of these celts or hatchets were found. In 1847, M. Boucher de Perthes published his "Antiquités Celtiques et Antédiluviennes," giving an account of these discoveries, but no one would listen to him. The united authority of theologians and geologists opposed an infallible veto on the reception of such ideas, and it must be admitted that M. Boucher de Perthes himself did his best to discredit his own discoveries by associating them with visionary speculations about successive deluges and creations of pre-Adamite men. At length Dr Falconer, the well-known palæontologist, who had brought to light so many wonderful fossil remains from the Sewalik hills in India, happened to be passing through Abbeville and visited M. Boucher de Perthes' collection. He was so much struck by what he saw that on arriving in London he spoke to Mr. Prestwich, the first living authority on the tertiary and quaternary strata, and Mr. Evans, whose authority was

FLINT HÂCHE,
From Moulin Quignon, Abbeville.
(Half the actual size.)

FLINT HÂCHE,
From St. Acheul, Valley of the Somme.
(Half the actual size.)

(From Lubbock's "Prehistoric Times.")

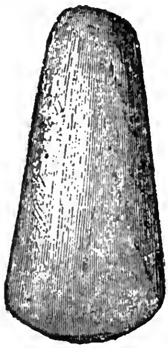
equally great on everything relating to the stone implements found in such numbers in the more recent or Neolithic period. He urged them to go to Abbeville and examine for themselves whether there was anything in these alleged discoveries. They did so, and the result was that on their return to England Mr. Prestwich read a paper to the Royal Society on the 19th May, 1859, which conclusively and forever established the fact that flint implements of unmistakable human workmanship had been found, associated with the remains of extinct species, in beds of the Quaternary period deposited at a time when the Somme ran at a level more than 100 feet higher than at present, and was only beginning to excavate its valley.

The spell once broken evidence poured in from all quarters, and although twenty-five years only have elapsed since Mr. Prestwich's paper was read, the number of stone and other implements worked by man, deposited in museums, is already counted by tens of thousands, and they have been found from Devonshire to India, in France, England, Germany, Spain, Italy, Greece, Northern Africa, Palestine, and Hindostan, and in fact wherever they have been looked for, except in northern countries which were buried under ice during the Glacial period. Some idea of the immense number of these rude implements may be formed from the fact that the valley system of one small river, the Little Ouse, which rises near Thetford and flows into the Wash after a course of twenty-five miles, has within little more than ten years yielded about 7,000 specimens.

FLINT HACHE.
From Hoxne, Suffolk.
(Half the actual size.)
(From Lubbock's "Prehistoric Times.")

They have been found in great abundance in the valley gravels of the Thames, Ouse, Wiltshire Avon, and in fact in all the river gravels and brick-earths of the south and south-east of England; and in those of the Somme, Oise, Seine, Loire, and all the principal river systems of France; and in less numbers, probably because they have been less looked for, in similar situations over an area extending from Central and Southern Europe to Madras and China. It is a remarkable fact about these river-drift implements that they are all nearly of the same type and found under similar circumstances, that is to say, in the gravels, sands, brick-earths, and fine silt or loess deposited by rivers which have either ceased to run, or which ran at levels higher than their present ones and were only beginning to excavate their present valleys. Also they are always found in association with remains of what is known as the quaternary, as distinguished from the recent or existing fauna, and which is characterized by the mammoth, the thick-nosed rhinoceros, and other well-known types of extinct animals. The general character of these implements is very rude, implying a social condition at least as low as that of the Australian savages of the present day. They consist mainly of the flake; the chopper or pebble, roughly chipped to an edge on one side; the scraper, used probably for preparing skins; pointed flints used for boring, and by far the most abundant and characteristic of all, the *hâche* or celt, a sharp or oval implement, roughly chipped from flint or, in its absence, from any of the hard stones of the district, such as chert or quartzite, and intended to be held in the hand and used without any haft or handle.

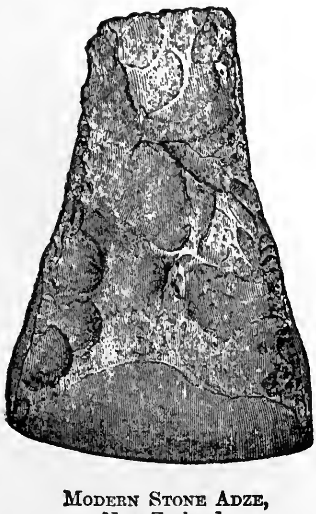
These *hâches* are evidently the first rude type of human tools, from which the later forms of the axe, adze, chisel, wedge, etc., have been derived by a very slow and lengthened process of evolution. They differ, however, in many essential respects, from the more perfect stone celts of later periods and of modern savages. The chipping is very rude, they are never ground or polished, the pointed end is that intended for use, the butt-end being left blunt, showing that the *hâche* was not hafted but held in the hand; while the converse is always the case with the finely-chipped or polished stone celts and hatchets of the Neolithic period, which, in its later stages, are to all intents and purposes similar to modern implements, only made of stone instead of metal. But these Palæolithic *hâches* are only one step in advance of the rude natural stone which an intelligent orang or chimpanzee might pick up to crack a cocoa-nut with, or to grub up a root from the earth, or an insect from a rotten tree.



Polished Stone Axe.
Neolithic.
(Half the actual size.)
(From Lubbock's "Prehistoric Times.")

At the same time there is not the remotest doubt as to their being the work of human hands. When placed side by side with the rudest forms of stone hatchets actually used by the Australian and other savages, it is difficult to detect any difference. If placed in an ascending series, from the oldest and rudest, to the finely-finished axes and arrow-heads of the period immediately preceding the use of metal, the progress may be clearly traced by insensible gradations. The blows given to bring the block to the desired shape

Flint Adze,
From Danish Kitchen-middens.

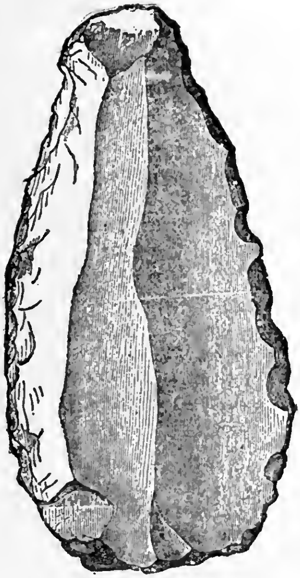


Modern Stone Adze,
New Zealand.

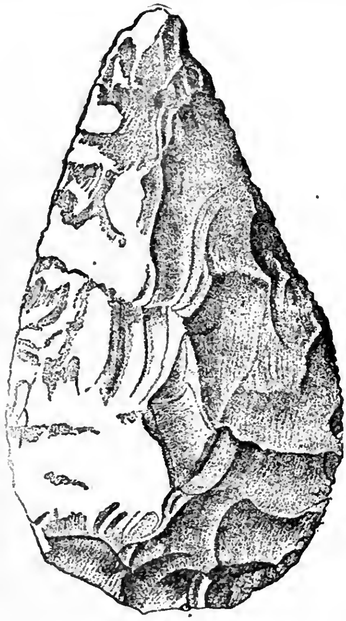
(From Lubbock's "Prehistoric Times.")

by intentional chipping have left distinct marks; and archæologists have succeeded, with a little practice, in fashioning similar implements from modern flints. In fact, forgeries have been made by workmen in localities where collectors were eager and credulous, though for-

DEVELOPMENT OF THE LANCE.



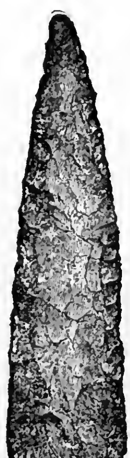
PALÆOLITHIC.
Mammoth Period.



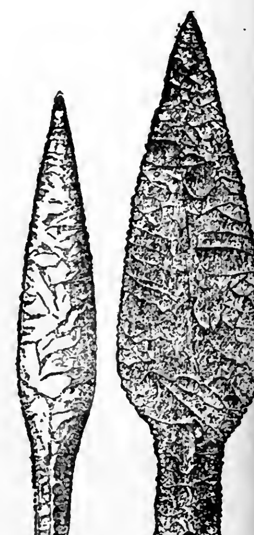
PALÆOLITHIC.
Mammoth Period.

PALÆOLITHIC.
Mammoth Period.

PALÆOLITHIC.
Reindeer Period.



EARLY NEOLITHIC.



LATE NEOLITHIC.

(From Lubbock's "Prehistoric Times."

tunately such forgeries are easily distinguished from genuine antiques by the different appearance of the old and recent fractures, and other signs which make it almost impossible to deceive an experienced eye. The conclusion, therefore, of one of our best archæologists may be safely accepted, that it is as impossible to doubt that these rude stone flakes and hatchets are works of human art, as it would be if we had found clasp-knives and carpenters' adzes.

The remains of human skeletons are, as might be expected, very rare in these river drifts, which have been formed under conditions where the preservation of such remains would be very unlikely. In fact, as Sir John Lubbock points out, the bones found in the river gravels are almost invariably those of animals larger than man, such as the mammoth and rhinoceros. Still a few human bones have been found, sufficient to show that these river-drift men were probably a dolichocephalic or long and narrow-headed race, with prominent jaws, massive bones, and great muscular strength, but still, although rude and savage, of an essentially human type, and going a very little way towards bridging over the gap between the savage and the ape.

A more complete view, however, of the conditions of human life at these remote periods is afforded by the evidence given by caves, where naturally the remains of man are much more abundant and much better preserved. Before entering, however, on the examination of this class of evidence, it may be well to give an instance which may help to familiarize the imagination with the vast periods of time which must have elapsed since Palæolithic man left these rude implements within reach of river floods.

Among the gravels in which Palæolithic *hâches* have been found, are some which cap the cliff at Bournemouth at a height of about 130 feet above the sea. This gravel can be traced in a gradual fall from west to east, along the Hampshire coast and the shores of the Solent to beyond Spithead, and was evidently deposited by a river which carried the drainage of the Dorsetshire and Hampshire downs into the sea to the eastward, and of which the present Avon, Test, and Itchen were tributaries. But for such a river to run in such a course the whole of Poole and Christ-church bays must have been dry land, and the range of chalk downs now broken through at the Needles must have been continuous. To borrow the words Evans in the "Ancient Stone Implements," "Who, standing on the edge of the lofty cliff at Bournemouth, and gazing over the wide expanse of waters between the present shore and a line connecting the Needles on the one hand and the Ballard Down Foreland on the other, can fully comprehend how immensely remote was the epoch when what is now that vast bay was high and dry land, and a long range of chalk downs, 600 feet above the sea, bounded the horizon on the south? And yet this must have been the sight that met the eyes of those primeval men who frequented the banks of that ancient river which buried their handiworks in gravels that now cap the cliffs, and of the course of which so strange but indubitable a memorial subsists in what has now become the Solent Sea."

Any attempt to assign a more precise date than the vague one of immense antiquity to these early traces of primeval man, had better be postponed until we have examined the more detailed and extensive body of evidence which has been afforded by the exploration of caves, to which the great discovery at Abbeville at once gave an immense impulse, and which has since been prosecuted in England, France, Belgium, and Germany, with the greatest ardor and success.

The caves in which fossil remains are found occur principally in limestone districts. They are due to the property which water possesses, when charged with a small quantity of carbonic acid, of dissolving lime. Rain falling on the earth's surface takes up carbonic acid from contract with vegetable matter, and a portion of it finds its way through cracks and crevices in the subjacent rock to lower levels, where it comes out in springs of hard water charged with carbonate of lime from the rock which it has dissolved. It has been calculated that the average rainfall on a square mile of chalk thus carries away about 140 tons of solid matter in a year. In this way underground channels are formed, some of which become large enough to admit of streams flowing through them, and even rivers, as is seen in the limestone district of Carinthia, where considerable rivers are swallowed up and run for miles beneath the surface. In this way caverns are formed, or sometimes a series of caverns, which represent the pools of the rivers which formerly flowed through them. Accumulations were formed at the bottom of these pools of whatever may have been brought down by the stream, and when, owing to changes in level or denudation of the gathering grounds, the rivers ceased to flow in the old channel, these pools became dry and were converted into caves, in which wild beasts and man found shelter and left their remains. The *dêbris* thus formed accumulated with a mixture of blocks which fell from the roof, and of red loamy earth consisting of the residue of the limestone rock insoluble in water, and of dust and mud brought in by winds and floods, and occasionally interstratified by beds of stalagmite, composed of thin films of crystalline carbonate of lime, deposited drop by drop by drippings through the rock forming the roof of the cave. These drippings form what are called stalactites, which hang like pendent icicles from the roof of caves, and as the drip falls from these it forms a corresponding deposit, known as stalagmite, on the floor below. The formation of this deposit is necessarily extremely slow, and it only goes on when the drops of water charged with a minute excess of carbonate of lime come in contact with the air; so that whenever the floor of the cave was under water no stalagmite could be formed. The alternations, therefore, of deposits of stalagmite represent alternations of long periods during which the cave was generally dry or generally flooded. During the dry periods, when the cave happened to be inhabited, the treadings on the floor would prevent the accumulation of an unbroken deposit of pure stalagmite, and the crystalline matter would be employed in forming a solid cement of the various *dêbris* into what is known as a breccia.

Another class of caves, or rock-shelters, has been formed along the sides of valleys bounded by cliffs, where the stratification is horizontal or nearly so; but the different beds vary much in hardness and permeability to water. The softer strata weather away more rapidly than the others, and thus form shallow caves or deep recesses in the face of the cliffs, with a floor of hard rock below and a roof of hard rock above, which afford dry and commodious shelters for any sort of animal, including man. In other respects they resemble the first class of caves in having their contents cemented into a breccia by the dripping of water charged with carbonate of lime from the roof, and, if the cave happened to be deserted for a long period, this deposit would in the same way form a bed of stalagmite and seal up securely everything below it. In some cases, also, the roof would fall in, and thus preserve everything previously existing in the cave for the investigation of future geologists.

With these general remarks readers will be able to understand the evidence afforded by the remains of man found in caverns. I will begin by taking as a typical case that of Kent's Cavern, near Torquay, because it is one of the earliest and best known, and all the facts concerning it have been verified by explorations carefully conducted by a committee appointed by the British Association in 1864, and which comprised the names of the most eminent authorities in geology and palæontology, including those of Sir Charles Lyell, Sir John Lubbock, Mr. Evans, Mr. Boyd Dawkins, Mr. Pengelley, and others.

The cave is about a mile east from Torquay harbor, and runs into a hill of Devonian limestone in a winding course, expanding into large chambers connected by narrow passages. The following is the series of deposits in descending order in the large chamber near the entrance:

1. Large blocks of limestone which have fallen from the roof.
2. A layer of black, muddy mould, three inches to twelve inches thick.
3. Stalagmite one foot to three feet thick.
4. Red cave-earth with angular fragments of limestone of variable thickness, but in places five to six feet thick.

In the black earth above the stalagmite were found a number of relics of the Neolithic or polished stone period, with a few articles of bronze and pottery, some of which appear to be of a date as late as that of the Roman occupation of Britain. Associated with these are bones of ox, sheep, goat, pig, and other ordinary forms of existing species, and there is an entire absence of any older fauna, or of any of the ruder forms of Palæolithic implements. When we get below the stalagmite into the underlying cave-earth, the case is entirely reversed. Not a single specimen of polished or finely-wrought stone, or of pottery, is to be found; a vast number of celts or *hâches*, scrapers, knives, hammer stones, and other stone implements, are met with, which are all of the rude Palæolithic type found in the river drifts, with a few bone implements such as harpoon-heads, a pin, an awl, and a needle, like those frequently met with in the caves of France and Belgium. Associated with these are a vast number of bones and teeth, all of which belong to the old quaternary fauna, of which many species have become extinct and others have migrated to distant latitudes.

The following is a list of the mammalian remains which have been found in this cave-earth below the stalagmite:

ABUNDANT.

The Cave Lion, a large extinct species of lion.
Cave Hyæna, " " hyæna.
Cave Bear, " " bear.
Grizzly Bear.
Mammoth (*Elephas primigenius*).
Rhinoceros (*Tichorinus*), woolly or thick-nosed extinct species.
Horse.
Bison.
Irish Elk.

Red Deer.
Reindeer.

Scarce.

Wolf.
Fox.
Glutton.
Brown Bear.
Urus.
Hare.
Lagomnys, tailless Arctic hare.
Water Vole.
Field Vole.
Bank Vole.
Beaver.
And one specimen of the Machairodus, or Great Sabre-toothed Tiger, which is one of the characteristic species of the upper Miocene and Pliocene formations.

These constitute a fauna which is characteristic of the Pleistocene, Quaternary, or Palæolithic period, and essentially different from that of the prehistoric or Neolithic period, which is practically the same as that now existing. Wherever remains of the mammoth, woolly rhinoceros, and cave bear are found, Palæolithic implements may be expected, and conversely. In fact Palæolithic man is as essentially part of the characteristic fauna of the Quaternary period, as the Palæotherium is of the Eocene, or the Deinotherium and Hipparion of the Miocene.

A large number of other caves have been explored in England, notably the Victoria Cave near Settle in Yorkshire, the Gower Caves in South Wales, the Brixham Cave in Devonshire, the Woking Cave in Somersetshire, and King Arthur's Cave in Herefordshire, and the results have been everywhere practically the same as those at Kent's Cavern. The same class of implements have been found and the same fauna, with the occasional addition of a few species, among which the hippopotamus is the most remarkable. Everywhere there is the same entire break between the Neolithic and the Palæolithic deposits, and the same evidence of great antiquity for the latter. It would appear as if in the British area some great geological change, such as submergence beneath the sea or invasion of the ice, had exterminated or driven away Palæolithic man, along with the mammoth, rhinoceros, cave bear, and other extinct animals of the Palæolithic fauna, and after a long lapse of time the area had again become habitable and been occupied by a newer race and by the recent fauna.

The same remark applies to the river drifts, which not in England only, but everywhere, appear to belong to a distinct period, vastly more ancient than any of the recent deposits in which Neolithic remains are found. So far, therefore, as the river drifts and British caves are concerned, all that we could say of the Palæolithic period is that it is of vast antiquity, and must have lasted for an immense time, as it was in force for the whole time requisite for rivers like the Somme or Avon, which drain small areas, to cut down their present valleys, often two or three miles wide, from the level of their upper gravels, which are in many places 100 to 150 feet above the level of the highest floods of the present rivers.

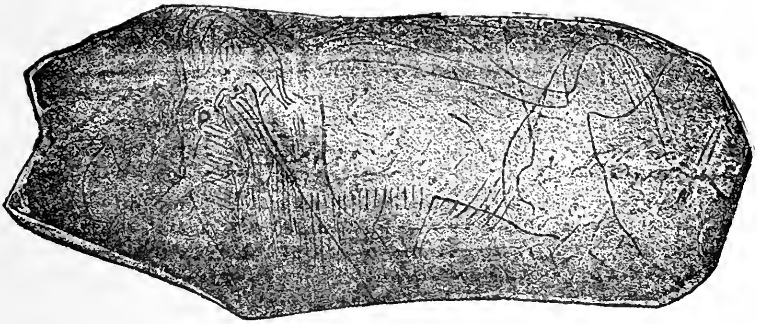
But the caves of France and Belgium supply us with more evidence, and enable us to trace the history of long periods of Palæolithic time, and study in detail the succession of changes that have occurred, and the habits, arts, and industries of the various tribes of primitive men who occupied these caves and rock-shelters at these remote periods. In fact, it may be said with truth that we know more about the men who chased the mammoth and reindeer in the South of France perhaps 50,000 years ago, than we do about those who lived there immediately before the classical era, or less than 5,000 years ago.

In certain provinces of France and Belgium it happens fortunately that there are extensive districts of limestone, in which caverns and rock-shelters are extremely abundant and full of Palæolithic remains in an excellent state of preservation. The abundance of such caves may be estimated from the fact that the cliffs, bounding one small river, the Vezère, in the department of Dordogne in the South of France, contain in a distance of eight or ten miles no fewer than nine different stations, each of which has given a vast variety of remains embedded in the breccias and cave-earths of their respective floors; and the small river Lesse in Belgium has been scarcely less prolific. Of the abundance of the human and animal remains found in such caverns it may be sufficient to say that one alone, that of Chaleux in the valley of the Lesse, is computed by Dumont to have yielded not less than 40,000 distinct objects.

The great abundance of remains thus collected, both of human bones and implements, and of animals contemporaneous with them, have made it possible to classify and arrange, in relative order of time, a good many of the subdivisions of the Palæolithic period. This has been done partly by the order of superposition and partly by the greater or less rudeness of the implements of stone and bone, and by the greater or less abundance of those animals of the quaternary fauna which appeared first and disappeared soonest. The result has been to show that the period when vast herds of reindeer roamed over the plains of Southern France up to the Pyrenees was not the earliest, but was preceded by a long period when the reindeer was scarce, and the remains of the mammoth, cave bear, and cave hyæna were more abundant than in the following ages. The implements of this period are of the earlier river-drift type and extremely rude, and there is an almost entire absence of instruments of bone.

Gradually as we pass upwards the more Southern forms of elephant, rhinoceros, antelopes, and great carnivora disappear, and the mammoth and cave bear become scarcer, while the reindeer becomes more and more abundant until at length it furnishes the chief source of food, and its horns one of the principal materials for the manufacture of implements. Concurrently with this change we find a progressive improvement in the arts of life, as shown by stone implements more carefully chipped into a greater variety of forms, and arrow and lance-heads, barbed harpoons, awls, and needles for sewing skins, made chiefly from the antlers of the reindeer.

At length we arrive at one of the most interesting facts disclosed by these researches, that during one of the later or reindeer periods of the Palæolithic era, many of the caves in the South of France, and also in Switzerland and Southern Germany, were occupied by a race who, like the Esquimaux of the present day, had a strong artistic tendency, and were constantly drawing with the point of a flint on stone or bone, or modeling with flint knives from horns and bones, sketches of the animals they hunted, scenes of the chase, or other objects which struck their fancy. These are exceedingly well done,

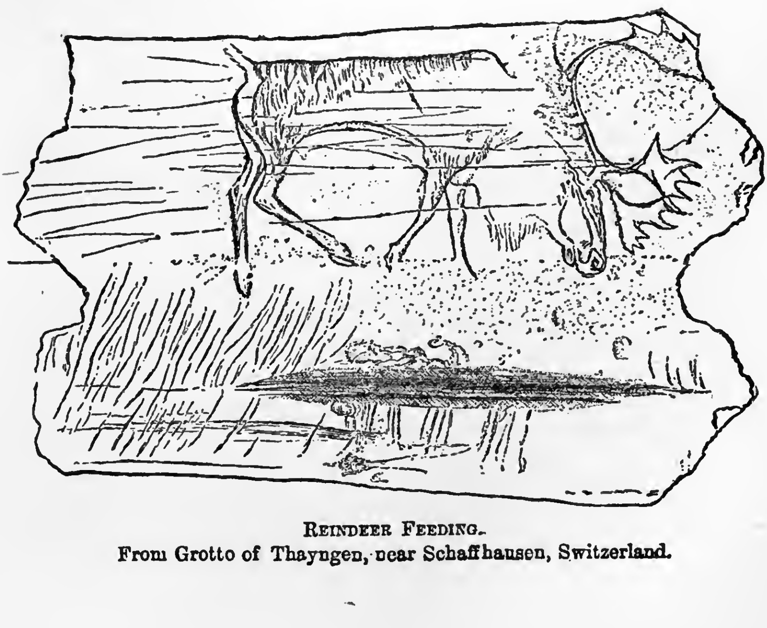


PORTRAIT OF MAMMOTH.

Drawn with a flint on a piece of Mammoth's ivory; from Cave of La Madeleine, Dordogne, France.

EARLIEST PORTRAIT OF A MAN, WITH SERPENT AND HORSES' HEADS.

From Grotto of Les Eyzies. Reindeer Period.



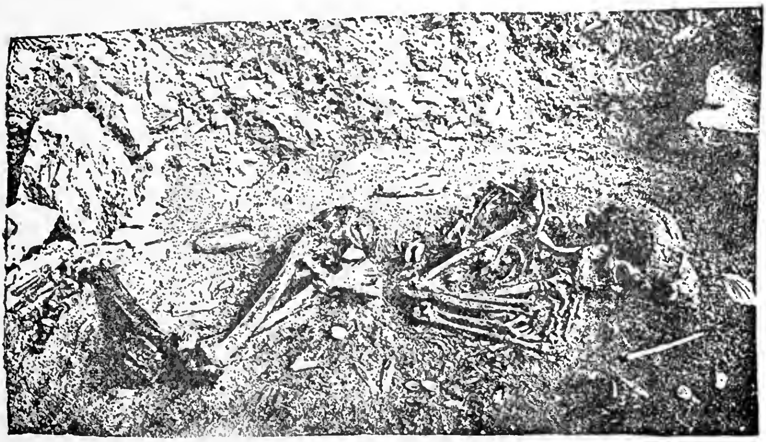
REINDEER FEEDING.

From Grotto of Thayngen, near Schaffhausen, Switzerland.

so that there is no difficulty in recognizing the animals intended to be represented, among which are the mammoth, cave bear, reindeer, wild horse, and wild ox. The sketch of the mammoth which is engraved on a piece of ivory, from the cave of La Madeleine in the valley of the Vezère, is particularly interesting, as it corresponds exactly with the mammoth whose body was found entire in frozen mud on the banks of a river in Siberia, and it sets at rest all possible question of man having been really contemporary with this extinct animal in the South of France.

The drawings and carvings of other animals, especially of the reindeer, are often extremely spirited, and one especially of a reindeer engraved on a bit of bone from a cave at Thayngen, near Schaffhausen in Switzerland, would do credit to any modern animal painter. A very few human figures are found among these primeval drawings, but strangely, while the animals are so well drawn, those of men are very inferior and almost infantine in execution. They are sufficient, however, to show that the savage of Périgord pursued the formidable aurochs, naked, armed with a lance or javelin, bearded on the chin but not on the rest of the face, and wearing his hair in a tuft on the top of the head.

We do not, however, depend on these drawings for evidence of the sort of men who inhabited these caves in Palæolithic days. A large



Mentone Skeleton. Palæolithic. Reindeer Period.

number of skulls and complete skeletons have been found in different caves, some of which have served as sepulchral vaults for families and tribes, while in others individuals have been crushed by falls of rock, or otherwise interred, and in a few cases skulls and bones have been found at great depths in river drifts, and in the loess, or fine glacial mud which fills up the valley of the Rhine and other areas over which the great Swiss glaciers when melting poured their turbid streams.

The most celebrated of these are:

The Neanderthal and Canstadt skulls, which are considered to belong to the oldest type, having been found in the lowest strata, which contain the rudest implements and the most archaic fauna. Of these the Neanderthal skull has attracted much attention from its singularly brutal appearance, having a very low and receding forehead, and a massive bony ridge over the eyes resembling that of the gorilla. But the brain is of fair capacity, and occasional skulls of a similar type occur at the present day, so that we are not warranted in saying that we have discovered the "missing link" between man and ape, especially as the Engis and other skulls of this period present less exceptional features. All we can safely say is that the oldest type of man known to us seems to have been characterized by long and narrow heads, prominent eyebrows, medium stature, and great thickness of bones and prominence of ridges denoting great muscular strength.

The discovery of a sepulchral chamber at Cro-Magnon in the valley of the Vezère, with several entire skeletons, gave evidence of another type which has been found elsewhere in caves of the same age, viz., newer than the earliest mammoth and cave bear age to which the oldest skulls are referred, but older than the subsequent reindeer age, and still characterized by great rudeness of implements. This is a remarkable type, for these savages were really a fine race of men, tall in stature and with well-developed brain. They are long-headed, but not more so than is often found in the best modern European skulls, and the average capacity of the skull exceeded that of most modern races, while their average height was not less than 5 ft. 10 in. for the men, and 5 ft. 6 in. for the women.

Another totally different race appears in caves of the same period or a little later, which is known as the Furfooz race, from a sepulchral cave in Belgium where a number of skeletons were discovered, but which appears to have been widely spread throughout Europe towards the middle of the Palæolithic period. The type of this race is almost exactly that of the modern Lapp, short in stature, averaging not above 5 ft., though strong and muscular, and with small round heads and high cheek bones. From this time forward, long and short-headed races, and intermediate types resulting probably from their intermixture, seem to have existed pretty much as they do at the present day, and the important conclusion to be drawn is, that even as far back as the early Glacial period, man had already existed long enough to develop different races, and in sufficient numbers to scatter wandering tribes of savage hunters widely over the earth and up to the verge of glaciers and the utmost confines of inhospitable regions.

In trying to fix anything like definite dates for man's existence upon earth, we must reverse the process by which we have proved the enormous antiquity of his earliest remains, and ascend step by step from the known to the unknown. The first step is that supplied by history.

Authentic Egyptian history begins with Menes, the first king who united the different provinces of Egypt into one empire.

The date of this event has been fixed by the best authorities, who have devoted their lives to the study of Egyptian texts and monuments, at about 5,000 years B.C., or say 7,000 years before the present time. Boeck makes it B.C., 5702, Unger 5613, Mariette 5004, Brugsch 4455, Lauth 4157, Lepsius, 3892, and Bunsen 3623.

It will be observed that the tendency of all the more recent investigations is to lengthen the date, and that of Mariette may be safely assumed as the *minimum* limit of time for the foundation of the Egyptian monarchy.

Now this date shows no trace of approach to a primitive and uncivilized state of things. On the contrary, Menes is related to have carried out a great engineering work by which the Nile was embanked, its course changed, and the new capitol city of Memphis built on the site reclaimed. His next successor, Tet, is credited with having written learned treatises on medicine and anatomy, and the earliest pyramid, that of Sakkara, was probably built by a king who ascended the throne only eighty-eight years after the death of Menes.

The annals and monuments of Chaldæa and China take us back to about 2,500 years B.C., or say for 4,500 years from the present time, and tell the same tale as those of Egypt of dense population and a high degree of civilization already established. In fact, it is evident that the great alluvial valleys of rivers such as the Nile and Euphrates have been inhabited for a number of centuries by a population who had emerged from the hunter and pastoral stage into that of agriculture, and had increased and multiplied until great cities were built and mighty monarchies founded, and who were in possession of most of the arts of civilized life. The Egyptian date which carries us back about 7,000 years is, however, by far the earliest upon which we can rely as an authentic record, and any glimmerings of history beyond this are obviously mythical.

Here, then, we take leave of history, and must explore our way upwards by the aid of archæology and geology.

The earliest historical civilizations were all acquainted with metals, chiefly in the form of bronze, which is an alloy of copper and tin, very hard, easily cast, and well adapted for every description of tool and weapon. Indeed, it has only been superseded by iron within recent historical times. But the Bronze Age was preceded by a long Neolithic period, when stone, finely wrought and often ground or polished, was used for the purposes to which metal was afterwards applied. The men of this Neolithic period were comparatively civilized; they had all the common domestic animals, the dog, horse, ox, sheep, goat, and pig; also some of the cultivated grains, as wheat and barley; they wore clothing and lived in villages. According to all appearance they were the first wave of the great migrations into Europe from Asia, and either occupied regions left empty by the last vicissitudes of the Glacial period, or conquered, and partly exterminated and partly intermixed with, the ruder savages of the Palæolithic period. Some think the Iberian or Basque people may be a remnant of this Neolithic race, who were driven westward by the later wave of Celtic migration just as the Celts were by the still later waves of Teutonic and Slavonic immigrants. Be this as it may, it is certain that a Neolithic people were spread very widely over the globe, as their remains of very similar character are found almost everywhere in Europe, Asia, and America, and always in association with the existing or most recent fauna and configuration of the earth's surface.

The difficulty in assigning any precise date for these remains arises very much from the fact that the Neolithic passed into the Bronze or historical civilization, at different times in different countries. The Australians, the Polynesians, and the Esquimaux were or are still in the Stone period, while steam-engines are spinning cotton at Manchester, and the most famous cities of Egypt and the East have been for centuries buried under shapeless mounds of their own ruins. It is probable that all Europe remained in the Neolithic stage for many centuries after the historical date of the commencement of the Egyptian empire.

Still there are some remains which may enable us to form an approximate conjecture of the time during which this Neolithic period may have lasted.

The two principal clues are furnished:

1. By the Danish mosses and kitchen-middens.
2. By the Swiss lake-dwellings.

In Denmark there are a number of peat mosses varying in depth from ten to thirty feet, which have been formed by the filling up of small lakes or ponds in hollows of the Glacial drift. Around the borders of these mosses, and at various depths in them, lie trunks of trees which have grown on their margin. At the present surface are found beech-trees, which are now, and have been throughout the whole historical period of 2,000 years, the prevalent form of forest vegetation in Denmark. Lower down is found a zone of oaks, a tree which is now rare and almost superseded by the beech. And still lower, towards the bottom of the mosses, the fallen trees are almost entirely Scotch firs, which have been long unknown in Denmark and when introduced will not thrive there. It is evident, therefore, that there have been three changes of climate, causing three entire changes in the forest vegetation of Denmark, since these mosses began to be formed. The latest has lasted certainly for 2,000 years and we cannot tell how much longer, so that some period of more than 6,000 years must be assumed for the three changes.

Now, it is invariably found that remains of the Iron Age are confined to the present or beech era, while bronze is found only in that of oak, and the Age of Stone coincides with that of the Scotch fir.

The kitchen-middens afford another memorial of the prehistoric age in Denmark. There are mounds found all along the sheltered sea-coasts of the main-land and islands, consisting chiefly of shells of the oyster, cockle, limpet, and other shell-fish, which have been eaten by the ancient dwellers on these coasts. Mixed up with these are the bones of various land animals, birds, and fish, and flint flakes, axes, worked bones and horns, and other implements, including rude hand-made pottery, The relics are very much the same as those found in the fir zone of the peat mosses, and although old as compared with the Iron or historical age, they do not denote any extreme antiquity. The shells are all of existing species, though the larger size of some of those found on the shores of the Baltic shows that the salt water of the North Sea had then a freer access to it than at present. The bones of animals, birds, and fish are also all of existing species, and no remains of extinct animals, such as the mammoth, or even of reindeer, have been found. By far the most common are the red deer, roe-deer, and wild boar. The dog was known, but appears to have been the only domestic animal.

Most of the stone implements are rude, but a few carefully-worked weapons have been found, and a few specimens of polished axes, which, with the presence of pottery and the nature of the fauna, show conclusively that these Danish remains are all of the Neolithic age and subsequent to the close of the Glacial period. In fact, similar shell mounds are found in almost all quarters of the globe where savage tribes have lived on the sea-coast, subsisting mainly on shell-fish, and they are probably still being formed on the shores of the

Greenland and Arctic Seas, and in Australia, and remote islands of the Pacific.

Human remains are scarce in these Danish deposits, but numerous skulls and skeletons have been found in tumuli which, from their situation and from stone implements being buried with the dead, may be reasonably inferred to be those of the people of the peat mosses and shell mounds. They denote a short race with small and very round heads, in many respects resembling the present Lapps, but with a more projecting ridge over the eye.

On the whole, all we can conclude from these Danish remains is that at some period, not less than 6,000 or 7,000 years ago, when civilization had already been long established in the valley of the Nile, rude races resembling the Lapps or Esquimaux lived on the shores of the Baltic, who, although so much more recent, and acquainted with the domestic dog, pottery, and the art of polishing stone, had not advanced much beyond the condition of the later cave-men of the South of France; and that this race was succeeded by one who brought in the much higher civilization of the Bronze Age.

The lake-dwellings of Switzerland give still more detailed and interesting information as to Neolithic times.

During a very dry summer in 1854, the Lake of Zurich fell below its usual level and disclosed the remains of ancient piles driven into the mud, from which a number of deer-horns and other implements were dredged up. This led to further researches, and the result has been that a large number of villages built on these piles has been discovered in almost all the Swiss lakes, as well as in those of Italy and other countries. On the whole, more than 200 have been discovered in Switzerland, and fresh ones are being constantly brought to light. They range over a long period, a few belonging to the Iron and even to Roman times; while the greater number are almost equally divided between the Age of Bronze and that of Stone. Some of them are of large size, and must have been long inhabited and supported a numerous population, from the immense number of implements found, which at one station alone, that of Concise on the Lake of Neufchâtel, amounted to 25,000. These implements consist mainly of axes, knives, arrow-heads, saws, chisels, hammers, awls, and needles, with a quantity of broken pottery, spindle-whorls, sinkers for nets, and other objects.

In the oldest stations, where no trace of metal is found, and the decay of the piles to a lower level shows the greatest antiquity, the implements are all of the Neolithic type, and the animal remains associated with them are all of the recent fauna. There are no mammoths, rhinoceroses, or reindeer; the wild animals are the red deer and roe, the urus, bison, elk, bear, wolf, wild cat, fox, badger, wild boar, ibex, and other existing species; and of domestic animals, the dog, pig, horse, goat, sheep, and at least two varieties of oxen. Birds, reptiles, and fish, were all of common existing species. Carbonized ears of wheat and barley have been found, as also pears and apples, and the seeds, stones, and shells of raspberry, blackberry, wild plum, hazel-nut, and beech nut. Twine, and bits of matting made of flax, as well as the occurrence of spindle-whorls, show that the pile-dwellers were acquainted with the art of weaving.

On the whole, these pile-villages show that a large population lived in Switzerland for a long time before the dawn of history, who had already attained a considerable amount of civilization at their first appearance, which went on steadily increasing down to the time of the Roman conquest. Various attempts have been made to fix an approximate date for the earliest of these pile-villages, but they have not been very successful. They have been based mainly on the amount of silting up which has taken place in some of the smaller lakes since the piles were driven in, as compared with that which has occurred since the Roman period. The best calculations appear to show that 6,000 or 7,000 years ago Switzerland was already inhabited by men who used polished stone implements, but how long they had been there we had no distinct evidence to show. Perhaps 10,000 years may be taken as the outside limit of time that can be allowed for the Neolithic period in Switzerland, Denmark, or any known part of Europe.

In Egypt, however, there is evidence of a much greater antiquity. Fragments of pottery, which was entirely unknown in the Palæolithic age, have been brought up by borings in the Nile Valley from depths which, at the average rate of accumulation there during the last 3,000 years of three inches and a half in a century, would denote an age of from 13,000 to 18,000 years. Looking at the dense population and high civilization of Egypt at the commencement of history, 7,000 years ago, it is highly probable that this time at least must have elapsed since the country was first occupied by a settled agricultural population as far advanced in the arts of life as the lake-dwellers of Switzerland.

Any calculation, however, of Neolithic time takes us back a very short step in the history of the human race. The Palæolithic period must evidently have been of vastly longer duration.

Any attempt to estimate this must depend entirely on geological considerations. Palæolithic man is part of the Quaternary fauna, which came in with the commencement and continued down to the close of the great Glacial period.

In carrying our researches further back, the possibility of assigning anything like a definite date for the existence of man depends, therefore, on the question whether it is possible to fix any approximate dates for the commencement and duration of this period.

In the first place, how do we know that there has been a Glacial period?

In England we are familiar with water, but not with ice; we therefore recognize at once the signs of the action of water. If we come across a dry channel, winding in alternating curves between eroded banks, and showing deposits of gravel and silt, we say without hesitation, "Here a river formerly ran." But if we had lived in Switzerland, we should recognize with equal certainty the signs of glacial action. Suppose any one visiting Chamouni walks up the valley to the foot of the Mer de Glace, where the Arve issues from the glacier, let us say in autumn, when the front of the glacier has shrunk back some distance, what does he see? Rounded and polished rocks, which seem as if they had been planed by a gigantic plane working downwards over them, and on these a mass of miscellaneous rubbish shot down as if from a dust-cart, consisting of stones of all sizes, some of them boulders as big as a house, scattered irregularly on a mass of clay and sand. When he looks more closely he will see that these stones are not rounded as they would be by running water, but blunted at their angles by a slow grinding action; and in many cases, both the stones and the rocks on which they rest are scratched and striated in a direction which is that of the glacier's motion. At the bottom of this rubbish-heap he will find the clay into which the rock has been ground by the full weight of the glacier, very stiff and compact; while if he look down the valley, he will see, on a hot day, a swollen and turbid river issuing from the melting ice and flooding the meadows, on which it will leave a deposit of fine mud. These are effects actually produced by ice; and wherever he sees them he can infer the former presence of glacier, as certainly as when he sees a bed of rounded pebbles he infers the former presence of running water. The planed rocks are commonly known as *roches moutonnées* from a fancied resemblance of their smooth, rounded hummocks to the backs of a flock of sheep lying down; the rubbish-heaps are called *moraines;* and the stiff bottom clay with boulders embedded in it is called the *grund-moraine*, till, or boulder clay; while the blunted and scratched stones are said to be glaciated.

These tests, therefore, *roches moutonnées*, moraines, boulders, and glaciated stones, are infallible proofs that whevever we find them there has been ice-action, either in the form of glaciers, or of icebergs, which are only detached portions of glanciers floated off when the glacier ends in the sea. Now, if our inquirer extends his view, he will find that these signs, the meaning of which he has learned at the head of the valley of Chamouni, are to be found equally in every valley and over the whole plain of Switzerland, up to a height of more than 3,000 feet on the slope of the opposite Jura range, while on the Italian side the Glacial drift extends far into the plains of Piedmont.

Extending our view still more widely, we find that every high mountain range in the Northern hemisphere has had its system of glaciers; and one great mountain mass, that of Scandinavia, has been the nucleus of an enormous ice-cap, radiating to a distance of not less than 1,000 miles, and thick enough to block up with solid ice the North Sea, the German Ocean, the Baltic, and even the Atlantic up to the 100 fathom line. This ice-cap, coalescing with local glaciers from the higher lands of England, Scotland, and Ireland, swept over their surface, regardless of minor inequalities of hill and valley, as far south as to the present Thames Valley, grinding down rocks, scattering drift and boulders, and, in fact, doing the first rough sub-soil ploughing which prepared most of our present arable fields for cultivation. The same ice-sheet spread masses of similar drift over Northern Germany, Sweden, Denmark, and the northern half of European Russia, and left behind it numerous boulders which must have trav eled all the way from Norway or Lapland.

If we cross the Atlantic we find the same thing repeated on a still larger scale in North America. A still more gigantic ice-cap, radiating from the Laurentian ranges, which extend towards the pole from Canada, has glaciated all the minor mountain ranges to the south up to heights sometimes exceeding 3,000 feet, and coalescing vast glaciers thrown off by the Rocky Mountains from their eastern flanks, has swept over the whole continent, leaving its record in the form of drift and boulders, down to the 40th parallel of latitude. It is difficult to realize the existence of such gigantic glaciers, but the proofs they have left are incontrovertible, and we have only to look to Greenland to see similar effects actually in operation. The whole of that vast country. where at former periods of the earth's history, fruit-trees grew and a genial climate prevailed, is now buried deep under one solid ice-cap, from which only a few of the highest peaks protrude, and which discharges its surplus accumulation of winter snow by huge glaciers filling all the fiords and pushing out into the sea with an ice-wall sometimes forty or fifty miles in length, from which icebergs are continually breaking off and floating away. A still more gigantic ice-wall surrounds the Southern Pole, and in a comparatively low latitute presented an insuperable barrier to the further progress of the ships of Sir J. Ross's expedition.

A still closer examination of the Glacial period shows that it was not one single period of intense cold but a prolonged period, during which there were several alternations, the glaciers having retreated and advanced several times with comparatively mild inter-glacial periods, but finally with a tendency on each successive advance to contract its area, until the ice shrank into the recesses of high mountains, where alone we now find it. Another noteworthy point is that during this long Glacial period there were several great oscillations in the level of sea and land.

Such was the Glacial period, and to assign its date is to fix the date when we know with certainty that man already existed, and had for some long though unknown time previously been an inhabitant of earth. Is this possible? To answer this question we must begin by considering what are the causes, or combination of causes, which may have given rise to such a Glacial period. When we look at the causes which actually produce existing glaciers, we find that extreme cold alone is not sufficient. In the coldest known region of the earth, in Eastern Siberia, there are no glaciers, for the land is low and level and the air dry. On the other hand, in New Zealand, in the latitude of England and with a mean annual temperature very similar to that of the West of Scotland, enormous glaciers descend to within 700 feet of the sea-level. The reason is obvious; the Alps of the South Island rise to the height of 11,000 feet above the sea, and the prevalent westerly winds strike on them laden with moisture from their passage over a wide expanse of ocean. In like manner, in the case of the Swiss Alps, the Himalayas, and other great mountain ranges, high land and moist winds everywhere make glaciers. Given the moist wind, any great depression of temperature, whether arising from elevation of land or other causes, will make it deposit its moisture in the form of snow, and the accumulation of snow on a large surface of elevated land must inevitably relieve itself by pushing down rivers of ice to the point where it melts, just as the rain-fall relieves itself by pouring down rivers to the point where the surplus water finds its level in the sea.

When the two conditions of high land and moist winds are combined, low temperature increases their effect, and the snow-fall consolidates into a great ice-cap, from which only the tops of the highest mountains project, and which pushes out gigantic glaciers far over surrounding countries and into adjacent seas. Such is now the case in Greenland, and was formerly the case in Scandinavia, where a huge sheet of ice radiated from it over Northern Germany as far as Dresden, filled up the North Sea, and, coalescing with smaller ice-caps from the highlands of Scotland, England, and Wales, buried the British Islands up to the Thames under massive ice. At the same period glaciers from the Alps filled the whole plain of Switzerland, and in North America the ice-cap extended from Labrador to Philadelphia.

The first remark to be made is that, as these phenomena depend primarily on moist winds, and only secondarily on cold, and as moist winds imply great evaporation and therefore great solar heat over extensive surfaces of water, all explanations are worthless which suppose a general prevalence of cold, either from less solar radiation, passage through a colder region of space, or otherwise. We must seek for a cause which is consistent with the general laws of Nature, and with the leading facts of the actual generation of glaciers at the present day.

Astronomers believe that they have discovered such a cause, in the theory first started by Mr. Croll, that the glaciation of the Northern hemisphere was due to a secular change in the shape of the earth's orbit, combined with the shorter changes produced by the precession of the equinoxes. The latter cause is due to the fact that the earth is not an exact sphere but slightly protuberant at the equator, and that the attraction of the sun on this protuberant matter prevents the axis round which the earth rotates from remaining exactly parallel with itself, and makes it move slowly round its mean position just as we see in the case of a schoolboy's top, which reels round an imaginary upright axis while spinning rapidly. This revolution in the case of the earth completes its circle in about 21,000 years, so that if summer, when the pole is turned towards the sun, occurred in the Northern hemisphere when the earth was in perihelion, or nearest the sun, and consequently winter when it was in aphelion, or furthest away from the sun, after 10,500 years the position would be exactly reversed, and winter would occur in perihelion and summer in aphelion; the Southern hemisphere then enjoying the same conditions as those of the Northern one 10,500 years earlier. And in another 10,500 years things would come back to their original position.

Now if the earth's orbit were an exact circle this would make no difference, all the four seasons would be of the same duration and would receive the same solar heat in both hemispheres, and if the orbit were nearly circular, so that the difference between the perihelion and aphelion distances was small, the effect would be small also. But if the orbit flattened out or became more eccentric, the effect would be increased. The time of traversing the aphelion portion of the annual orbit would become longer and that of traversing the perihelion portion shorter, as the orbit departed from the form of a circle and became more elliptic. Whenever, therefore, the North Pole was turned away from the sun in aphelion, the winters would be longer than the summers in the Northern hemisphere, and conversely, the summers would be longer than the winters when, after an interval of 10,500 years, precession brought about the opposite condition of things, in which winter occurred in perihelion.

At present the earth's orbit is nearly circular, and the Northern hemisphere is nearest the sun in winter and furthest from it in summer, but the difference is only about 3,000,000 miles, or a small fraction of the total mean distance of 93,000,000 miles, which makes the winter half of the year shorter than the summer half by nearly eight days.

But mathematical calculations show that under the complicated attractions of the sun, moon, and larger planets, the eccentricity of the earth's orbit slowly changes at long and irregular intervals, but always within fixed limits, increasing up to a certain point and then diminishing till it approaches the circular form, when it again increases.

The *maximum* limit of eccentricity makes the difference between the greatest and least distances of the earth from the sun range between 12,000,000 and 14,000,000 miles, which is four or five times as great as at present; and with this eccentricity, and winter in aphelion in the Northern hemisphere, the winter half of the year in Northern latitudes would be twenty-six days longer than the summer half, instead of eight days shorter as at present. In this state of things the quantity of heat received daily from the sun in winter would be such as to lower the temperature of the whole Northern hemisphere by 35° Fahrenheit, and reduce the average January temperature of England from 39 to 4°, while the mean summer temperature would be about 60° higher than at present. But this summer heat, derived from solar radiation, would not counteract the cold of winter, for all moisture during winter being accumulated in ice, and snow, most of the solar heat of summer would be expended in supplying latent heat to melt a portion of this frozen accumulation, and dense fogs would intercept a large amount of the solar radiation.

After 10,500 years this state of things would be entirely reversed, and with twenty-six days more of summer, and the earth 12,000,000 miles nearer the sun in winter, the Northern hemisphere would enjoy something like perpetual spring. There can be no doubt that these are real causes, and the only difficulty is to account for their not having been more invariable in their operation and given us a constant succession of Glacial periods since the commencement of geological time, whenever the eccentricity became great, which occurs at irregular periods, but practically about three times in every 3,000,000 years. The answer is that the effects would only occur when the other conditions were present, viz., high land, moist winds, and an absence of oceanic currents of warm water like the Gulf Stream. The latter is one of the main causes which affect temperature. The difference of temperature between the equatorial and polar regions causes a constant overflow of heated air from south to north, which is replaced by an indraught of colder air from north to south, which, owing to the greater velocity of the earth's rotation towards the equator, takes the form of trade-winds blowing constantly from a more or less easterly direction. These winds, sweeping over the Atlantic Ocean, raise its level at its western barrier, and the accumulation deflected by America flows off in a current which extends to the western shores of Europe and carries mild winters into the extreme North. In the Orkney and Shetland Islands, which are nearly in the same latitude as Cape Farewell in Greenland, there is so little ice that skating is a rare accomplishment, and curling, the roaring game which is so popular some degrees further south, is quite unknown. If the Gulf Stream were diverted, and the highlands of Scotland upheaved to the height of the Alps of New Zealand the whole country would again be buried under glaciers pushing out into the Atlantic and German Ocean.

These considerations may show why every period of great eccentricity was not necessarily a Glacial period, though under certain conditions it must inevitably have been so, and geologists are generally agreed that the last period of the sort must have been one of the main causes of the great refrigeration which set in over the whole Northern hemisphere towards the close of the Pliocene period, and continued until recent times. But in this case we can fix the date with great accuracy, for calculation shows that the last period of great eccentricity began 240,000 years ago, and lasted 160,000 years. For the last 50,000 years the departure of the earth's orbit from the circular form has been exceptionally small. We may suppose the Glacial period, therefore, to have commenced 240,000 years ago, come to its height 160,000 years ago, and finally passed away 80,000 years before the present time.

These dates receive much confirmation from conclusions drawn from a totally different class of facts. A bed of existing marine shells of Arctic type, apparently belonging to one of the latest phases of the Glacial period, has been found on the top of a hill in North Wales which is now 1,100 feet above the sea-level, and the same marine drift seems to extend to a height of upwards of 2,000 feet. There must, therefore, have been a depression of the land sufficient to carry it many fathoms below the sea, and a subsequent elevation sufficient to carry the sea bottom up to a height of certainly 1,100 and probably over 2,000 feet. In all probability, these movements were very slow and gradual, like those now going on in Greenland and Scandinavia, for there are no signs of earthquakes or volcanic eruptions in the district; and it is probable that pauses occurred in the movements, and a long pause when subsidence had ceased before elevation began. Without taking these pauses into account, and assuming the elevation only just completed, and that Sir C. Lyell's average of two and a half feet a century is a fair rate for these slow movements, it would have required 50,000 years of continued elevation to bring these shells, and 80,000 years to bring the marine drifts, up to their present height above the sea; and a similar period previously must be allowed for their submergence. We may fairly conclude, therefore, that upwards of 100,000 years have elapsed since these shells lived and died at the bottom of the sea towards the close of the Glacial period, which corresponds very well with the date assigned by astronomical calculations.

Again, another attempt to fix a date for the close of the Glacial period has been made by Monsieur Forel, a Swiss geologist, from actual measurements of the quantity of suspended matter poured into the Lake of Geneva by the Rhone, and the area of the lake which has been silted up since it was filled by ice. It is evident that this silting up at the head of the lake could only begin when the great Rhone glacier, which once extended to the Jura Mountains, had shrunk back into its valley far enough to pour its river into the lake. M. Forel's calculations give 100,000 years as the probable time required for the river to silt up so much of the lake as is now converted into dry land. The data are somewhat vague, as on the one hand the rate of deposition may have been greater when a large mass of ice and snow was being melted, while on the other hand it may have been less, while the glacier still occupied the valley almost to the head of the lake and the Rhone had only a course of a few miles. All that can be said, therefore, is that it gives an approximate date for the close of the Glacial period which, like that derived from rates of depression and elevation, corresponds wonderfully well with the date required by Croll's theory.

Now, whether the date be a little more or a little less, it is clear that man existed on earth throughout a great part, if not the whole, of the Glacial period. He had existed a long while in conjunction with a fauna of more Southern and African aspect, before the reindeer migrated in vast herds into Southern France. His remains are found in caves and river drifts associated with those of hippopotamus, an animal which could by no possibility have lived in rivers which for half the year were bound hard in ice. Such remains must therefore of necessity date either from a period before the great cold had set in, or from some inter-glacial period prior to the great cold which drove the reindeer, musk ox, glutton, and Arctic hare as far south as the slopes of the Pyrenees.

In England we can trace distinctly at least four successions of boulder clays, that is of the ground moraines of land ice, separated by deposits of drifts, sands, and brick-earths, formed while the glaciers were retreating and melting; and a number of the Palæolithic implements have been found in what was undoubtedly part of the period of the second or great chalky boulder clay, which overspreads the southern and eastern counties of England up to the Thames Valley. The discovery of Palæolithic remains in the deposit of St. Prest, near Chartres, makes it almost certain that some at least of the ruder instruments must date back to the very beginning of the Glacial period, and all the evidence points to the conclusion that man was living during the many alternations of climate of that period, and whenever the glaciers retreated, followed them up closely.

Thus far we have been going on certain and ascertained facts, confirmed by such numerous and well-authenticated proofs that doubt is impossible. But we get on less certain ground when we try to trace back human origin to more remote periods. As regards this question, we must begin by describing shortly the geological periods during which the existence of man may have been possible. It is useless to go back beyond the Chalk, which was deposited in a deep ocean and forms a great break between the modern and the Secondary period, in which latter reptiles predominated, and mammalia are only known by a few remains of small insectivorous and marsupial animals.

The inauguration of the present state of things commences with the Tertiary period. This has been divided into three stages: the Eocene, in which the first dawn appears of animal life similar in type to that now existing; the Miocene, in which there is a still greater approximation to existing forms of life; and the Pliocene, in which existing types and species become preponderant. Then comes the Pleistocene or Quaternary, including the great Glacial period, during which the whole marine and nearly the whole terrestrial fauna are of existing or recently extinct species, though very different in their geographical distribution from that of the present day. And finally we arrive at the recent period, when the present climate and the present configuration of lands, seas, and rivers, prevail with very slight modifications, and no changes have taken place either in the specific character or geographical distribution of life, except such as can be clearly traced to existing causes such as the agency of man.

This is the geological frame-work into which we have to fit the history of man's appearance upon earth. We have traced him through the recent and Quaternary, can we trace him further into the Tertiary? Speaking generally we may say that the Eocene period was that in which Europe began to assume something like its present configuration, and in which mammalian life, of the higher or placental type, began to supplant the lower forms of marsupial life which had preceded them. But these higher types were for the most part of a more primitive or generalized character than the more specialized types of later periods, and the highest order, that of the *primates*, which includes man, ape, and lemur, was, as far as is yet known, represented only by two or three extinct lemurian forms.

The plan on which Nature has worked in the evolution of life seems always to have been this: she begins by laying down a sort of ground plan, or generalized sketch of a particular form of life, say first of vertebrata, then of fish, then of reptiles, and finally of mammalian life. This sketch resembles the simple theme of a few notes on which a musician proceeds to work out a series of variations, each surpassing the other in complication and specialized development in some particular direction. Now, in the Eocene period we are in the stage of the theme and first simple variations of the mammalian melody. It hardly seems likely, therefore, that a creature so highly specialized as man, even in his most rudimentary form, should have existed, and in the absence of any direct evidence to the contrary, it is safe to assume that his first appearance must have been of later date.

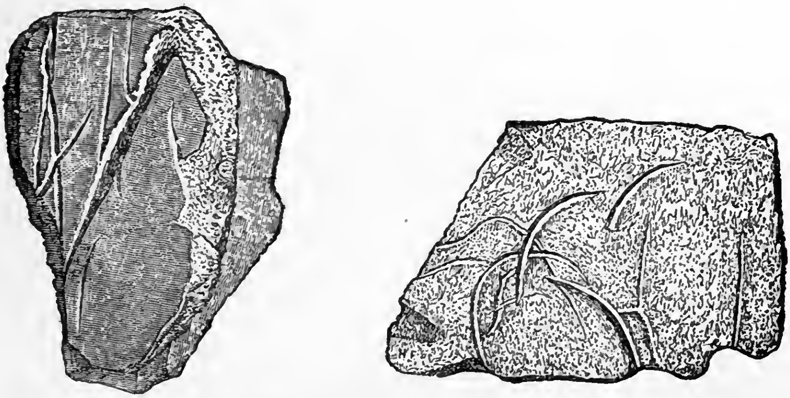
But when we come to the Miocene and Pliocene periods, the case is different. It is true that in the Miocene the specialization of certain families, as for instance that of the horse, had not been carried out to the full extent, and that all the species of Miocene land-mammals and several of the genera are now extinct. But there were already true apes and baboons, and even two species of anthropoid ape, one of which, the Dryopithecus, whose fossil remains were found in the South of France, was as large as a man, and has been considered by some anatomists as in some respects superior to the chimpanzee or gorilla.

Now, wherever anthropoid apes lived it is clear that, whether as a question of anatomical structure or of climate and surroundings, man, or some creature which was the ancestor of man, might have lived also. Anatomically speaking, apes and monkeys are as much special variations of the mammalian type as man, whom they resemble bone for bone and muscle for muscle, and the physical animal man is simply an instance of the quadrumanous type specialized for erect posture and a larger brain. The larger brain, implying greater intelligence, must also have given him advantages in contending with outward circumstances, as for instance, by fire and clothing against cold, which might enable him to survive when other species succumbed and became extinct.

If he could survive, as we know he did, the adverse conditions and extreme vicissitudes of the Glacial period, there is no reason why he might not have lived in the semi-tropical climate of the Miocene period, when a genial climate extended even to Greenland and Spitzbergen, and when ample forests supplied an abundance of game and edible fruits. The same reasons apply, with still greater force, to the Pliocene period, when existing types and species had become more common and when a mild climate still prevailed. The existence of Tertiary man must antecedently be pronounced highly probable; but probabilities are not proofs, and the fact of such existence must be determined by the evidence. All that can be said is that while there ought to be great caution in admitting as established a fact of such importance, there ought to be no determined predisposition to disbelieve it, like that which for so many years retarded the acceptance of the evidence for Palæolithic man. On the contrary, the fact that man existed in such numbers and under such conditions as have been described in the Quaternary period, establishes a strong presumption that his first appearance must date from a much earlier period.

Let us see how the evidence stands. Undoubted stone implements, and bones bearing traces of cuttings by flint knives, have been found in strata at St. Prest, near Chartres, which were always considered to be Pliocene. Since the discovery, however, some geologists have contended that these strata are not Pliocene, but of the earliest Quaternary or perhaps a transition period between Pliocene and Quaternary. This evidence cannot, therefore, be accepted as conclusive for anything more than proof that man's existence extends at any rate over the whole Quaternary period, comprising the vast glacial and inter-glacial ages which have effected such changes in the earth's surface.

The next piece of evidence is from Italy, where bones of the Balænotus, a sort of Pliocene whale, have been discovered in strata undoubtedly Pliocene, which bear marks of incisions which to all appearance must have been made by flint knives employed in hacking off the flesh. Doubts were thrown at first on this, as it was thought that possibly fish, or some gnawing animal like the beaver, might have



Incised Bones of Balænotus. Pliocene. From Monte Aperto, Italy. Figured by Quartrefages, "Hommes Fossiles et Hommes Sauvages," p. 93.

cut the grooves with their teeth. But later specimens have been found on which the cuts have a regular curvature which could not have been made by any teeth, and present precisely the same appearance as the cuts which are so commonly found on the bones of reindeer and other animals in hundreds of Palæolithic caves.

M. Quatrefages, who is a very eminent and at the same time very cautious authority, says, in his last work on the subject published in 1884, "Hommes Fossiles et Hommes Sauvages," that "the most incredulous must be convinced. The hand of man armed with a cutting instrument could alone have left marks of this sort on a plain surface. It is evident that some horde of savages of these remote times has found the carcase of this great cetacean stranded on the shore, and cut the flesh off with stone knives just as the savages of Australia do at the present day." In fact incredulity only exists because this is as yet a solitary instance of Pliocene man, and scientific men, feeling that if true, further evidence must soon be found, very properly endeavor to keep their judgment in suspense.

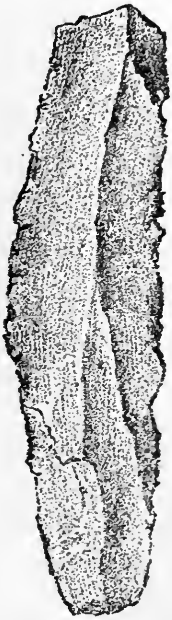
If these bones of the Balænotus really bear marks of human tools, the spectacle which might have been witnessed on the shore of the Pliocene sea perhaps 500,000 years ago, must have closely resembled that given by Sir John Lubbock from a description by Captain Grey of a recent whale feast in Australia. "When a whale is washed on shore it is a real godsend to them. Fires are immediately lit, to give notice of the joyful event. Then they rub themselves all over with blubber, and anoint their favorite wives in the same way; after which they cut down through the blubber to the beef, which they sometimes eat raw and sometimes broil on pointed sticks. As other natives arrive they 'fairly eat their way into the whale, and you see them climbing in and about the stinking carcass, choosing tidbits.' For days 'they remain by the carcass, rubbed from head to foot with stinking blubber, gorged to repletion with putrid meat—out of temper from indigestion, and therefore engaged in constant frays—suffering from a cutaneous disorder by high feeding—and altogether a disgusting spectacle. There is no sight in the world,' Captain Grey adds, 'more revolting than to see a young and gracefully-formed native girl stepping out of the carcase of a putrid whale.'"

FLINT S RAPER. From Thenay. Miocene Figured by Quatrefages "Hommes Fossiles et Hommes Sauvages," p. 92.

The evidence for Miocene man is much of the same character; very strong and conclusive as far as it goes, but resting on too few instances to be universally accepted. In 1868 the Abbé Bourgeois laid before the Anthropological Congress at Paris certain flints which he had found *in situ* in undoubted Miocene strata at Thenay, in the Beauce, near Blois. They were received with general incredulity, and the traces of human design were denied. The Abbé, however, persisted, and having made fresh discoveries the subject was referred to the next meeting of the Congress at Brussels, who appointed a commission of fifteen of the most eminent European authorities in such matters to report upon it. Nine reported that some of the flints showed undoubted traces of human workmanship, five were of an opposite opinion, and one was neutral. Since then fresh objects have been found and M. Quatrefages, who had formerly been doubtful, says in his recent work: "These new objects, and especially a scraper which is one of the most distinctly characterized of that class of implements, have removed my last doubts." And certainly, if the figures given at page 92 of his "Hommes Fossiles et Hommes Sauvages" correctly represent the original implements, and they really came from Miocene strata, doubt is no longer possible. The evidence of design in chipping into a determinate shape is quite as clear as in the similar class of implements from Kent's Cavern or the Cave of La Madeleine. They must either have been chipped by man, or as Mr. Boyd Dawkins supposes, by the Dryopithecus or some other anthropoid ape which had a dose of intelligence so much superior to the gorilla or chimpanzee as to be able to fabricate tools. But in this case the problem would be solved and the missing link discovered, for such an ape might well have been the ancestor of Palæolithic man.

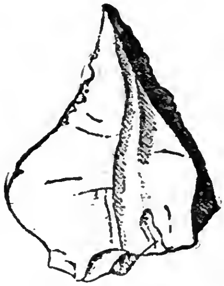
MIOCENE IMPLEMENTS FROM THENAY COMPARED WITH UNDOUBTED PALÆOLITHIC IMPLEMENTS FROM QUATERNARY CAVES AND DRIFTS.

MIOCENE.



QUATERNARY. Chaleux, Belgium. Reindeer Period. Congrès Préhistorique, Bruxelles, 1872.

SCRAPER, OR RUDE KNIFE. Thenay. Miocene. Quatrefages, p. 92.



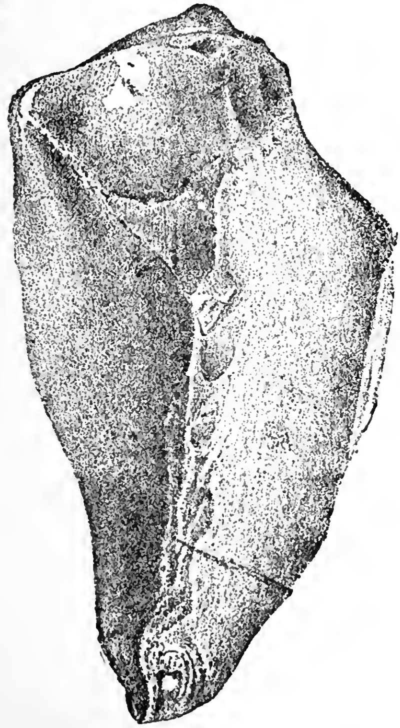
BORER, OR AWL. Thénay. Miocene. Congrès Préhistorique, Bruxelles, 1872.

SCRAPER. Thenay. Miocene. Quatrefages, p. 92.

QUATERNARY. From Le Moustier.

QUATERNARY. Mammoth Period. River Drift, Mesvin, Belgium. Congrès Préhistorique, Bruxelles, 1872.

The next instance is from the valley of the Tagus, where flint implements were alleged to have been discovered by an eminent Portuguese geologist, Señor Ribeiro, in Miocene strata. The subject was fully discussed on the spot, at a meeting of the Anthropological Congress at Lisbon in 1880. The general opinion seemed to be that some of the implements showed undoubted traces of human design, but some good authorities remained sceptical; and although there was no doubt that they were found in Miocene strata, it was thought possible that flints of Quaternary age might have fallen into fissures, or been mixed up with Miocene sands by floods at some very remote period, and thus become encrusted in a Miocene matrix.



TERTIARY HACHE.
From Miocene strata of Tagus Valley.
(Half the actual size.)
Quartrefages "Hommes Fossiles et Hommes Sauvages."

The verdict here, therefore, must be "Probable, but not proven." The same will apply to the alleged discovery of a human skull in California, buried under six distinct layers of hardened volcanic ashes, and certainly of Pliocene date, if not earlier. Whitney, the Director of the Geological Survey of the United States, and other American geologists, believe this skull to be Pliocene, but doubts have been thrown on its authenticity, and European geologists do not generally accept it.

A human bone is described by Lyell, which was found near Vicksburg in a side valley of the Mississippi, associated with bones of the extinct Mastodon and Megalonyx. But, although undoubtedly of great antiquity, there is no proof that it does not belong to the Quaternary period, especially as the mastodon seems to have lived until comparatively recent times in America, its remains being often found in recent bogs and peat mosses.

The same remark will apply to the skull which was found in digging a well at New Orleans, under six distinct layers of cypress forests such as are now growing on the surface, showing as many periods of successive subsidences, subsequent elevations, and stationary periods long enough to allow of a forest growth of many generations of large trees. Here again the antiquity must be very great, but we have no reason to carry it back into Tertiary periods, or beyond the recent period when the Mississippi began to flow in its present course and form its present delta.

Human remains have also been discovered in caves in Brazil associated with bones of extinct animals, but we have no clear information as to the time when these animals became extinct, or as to the exact order of superposition in which the human skulls and implements were found, and the occurrence of a polished stone celt in the same cave throws still more doubt on their extreme antiquity.

The existence of Tertiary man must for the present be considered as resting on three instances:

1. The undoubted flint implements and cut bones (including those of the *Elephas meridionalis*, a Pliocene and Miocene species) of St. Prest.
2. The cut bones of the Balænotus from the Pliocene strata of Monte Aperto in Italy, the cuts on which appear to have been undoubtedly made by the hand of man armed with a sharp cutting stone implement.
3. The flints from the Miocene strata of Thenay, some of which show unmistakable signs of having been split by fire and chipped into shape by design.

On the other hand the evidence is entirely negative, that a large number of fossil animal remains have been found in various parts of the world, specially in the Pliocene of the Cromer forest bed, and the Miocene of the Sewalik hills, Pikermi and Nebraska, without finding any trace of man. This is true, and is sufficient to make us require great caution in admitting as fully established a fact of so much importance, which would carry back the antiquity of man from one or two hundred thousand years to at least a million. But the example of Quaternary man shows the danger of trusting too exclusively to negative evidence. Thirty years ago the negative evidence against his existence was considered conclusive. Now his remains have been found over the whole world and in thousands of instances.

It must be remembered, also, that remains of Tertiary man are not likely to be abundant. If man was then living, it was probably in fewer numbers and in more limited areas. The pressure of population had not yet driven wandering hordes to follow sea-coasts and cross rivers and mountains in pursuit of food. Probably at this early period man lived more on fruits, and therefore required fewer implements, and his intelligence was less, so that he had less power of fashioning them. For the purposes for which his Palæolithic descendents chipped stones into shape, he may have used natural stones which would often answer the purpose, but which, when thrown away, would leave nothing by which they could be recognized.

If the forests now inhabited by the gorilla and chimpanzee were submerged and again elevated, no trace would be found of the existence of animals which had built rude nests, used broken branches of trees as clubs, and cracked cocoa-nuts with hammer stones.

But above all, the surface of these older strata has been so much denuded, that the situations in which alone we might expect to find remains of man have almost entirely disappeared. Ninety-nine hundredths of our Quaternary implements come from river drifts or caves. Where are the Pliocene or Miocene rivers or caves? They have disappeared amidst the revolutions of the earth's surface and the constant denudation which wastes continents away. The negative evidence would be strong if we could point to caves filled with bone-breccias of a Pliocone or Miocene fauna, in which no trace was found of human remains. But it is weak as against even a single well-ascertained instance, if it merely amounts to such remains not being frequently found where we could hardly expect to find them. And it is weak against the strong presumption that when Quaternary man is found in such numbers and under such conditions, spread over wide areas in inhospitable climates, he must have had his first origin in earlier times. It is, therefore, in the highest degree probable that this origin must have been in Tertiary times, when we know as a certain fact that large anthropoid apes were already in existence.

If this were so, what would it teach us as to the date of man's appearance?

Reckoning by the thickness of the different stratified deposits which make up the earth's crust, and assuming the average rate of their deposition, or what is the same thing, the average rate of waste of land surface to have been the same throughout, the whole Tertiary period carries us back barely one-twentieth part of the way towards the first beginnings of fossil-bearing strata. That is, if 100,000,000 years have elapsed since the earth became sufficiently solidified to support vegetable and animal life, the Tertiary period may have lasted for 5,000,000 years; or for 10,000,000 years, if the life-sustaining order of things has lasted, as Lyell supposes, for at least 200,000,000 years. Even if we take the shorter period, the time is ample for the enormous changes which have taken place since the commencement of the Eocene period. The average rate of denudation over the globe has been taken at about one foot in 3,000 years, from actual calculations of the average amount of solid matter carried down by the Mississippi and other great rivers. Now at this rate it would take only 2,000,000 years to wear the whole of Europe down to the sea-level, and, in the absence of any compensating movements of elevation, the whole of North America would be washed away and deposited in strata at the bottom of the Atlantic and Pacific Oceans in less than 3,000,000 years.

If, therefore, the origin of man could be traced down to the middle Miocene, or even to the date of the great anthropoid Dryopithecus of Southern France, we should have to assume a period for his existence of probably between one and two millions of years, a mere fraction of the time since the earth became the abode of life and existing causes operated to bring about geological formations.

As regards the habits and manners of Quaternary man we know very little that is positive, and can only gather some vague indications from the relics of caves and river drifts. These, however, are sufficient to establish with certainty that the law of his existence has been one of continued progress. The older the remains, the ruder are the implements and the fewer the traces of anything approaching to civilization. In the Neolithic period man is comparatively civilized. He has domestic animals and cultivated plants; he has clothing and ornaments, well-fashioned tools and pottery, and permanent dwellings. He lives in societies, builds villages, buries his dead, and shows his faith in a future life by placing with them food and weapons. As we ascend the stream of time these indications of an incipient civilization disappear. The first vestige of the domestic animals is found in the dog which gnawed the bones of the Danish kitchen-middens, and of the earliest Swiss lake-dwellings. When fairly in Palæolithic times even the dog disappears, and man has to trust to his own unaided efforts in hunting wild animals for food.

Weapons and implements become more and more rude until, in the oldest deposits, we find nothing but roughly-chipped hatchets, arrow-heads, flakes, and scrapers. Implements of bone, such as barbed harpoons, borers, and needles, which are abundant in the midde Palæolithic or reindeer period, become ruder and disappear. Pottery, which is extremely abundant in the Neolithic period, either disappears altogether or becomes so scarce that it is a moot question whether a few of the rudest fragments found in caves are really Palæolithic. If so, they clearly date from the later Palæolithic, and pottery was unknown in the earlier Palæolithic times.

Judging from the portraits engraved on bone during the reindeer period, Palæolithic man pursued the chase in a state of nature, though from the presence of bone needles it is probable that the skins of animals may have been occasionally sewed together by split sinews to provide clothing. There can be no doubt that his habitual dwelling was in caves or rock-shelters. Here was his home, here he took his meals and allowed the remains of his food to accumulate. His staple diet consisted of the contemporary wild animals, the mammoth, the rhinoceros, the cave bear, the horse, the aurochs, and the reindeer. Even the great cave lion was occasionally killed and eaten, and the fox and other smaller animals were not despised; while among tribes skilled in the use of the bow and arrow, birds were a common article of food, and fish were harpooned by those who lived near rivers. Wild fruit and roots were also doubtless consumed, and from the formation of his teeth and intestines it is probable that if we could trace the diet of the earliest races of men we should find them to have been frugivorous, like their congeners the anthropoid apes.

The abundance of wild animals and the long period for which hunting savages inhabited the same spots may be inferred from the fact that at one station alone, that of Solutré in Burgundy, it is computed that the remains of no less than 40,000 horses have been found. All the long bones of the larger animals have been split to extract the marrow, which seems, as with the modern Eskimos and other savages, to have been a great delicacy, and also used for softening skins for the purpose of clothing.

Among the split bones a sufficient number of human bones have been found to make it certain that Palæolithic man was, occasionally at least, a cannibal; and in several caves, notably that of Chaleux, in Belgium, these bones, including those of women and children, have been found, charred by fire, and in such numbers as to indicate that they had been the scene of cannibal feasts. It is a remarkable fact that cannibalism seems to have become more frequent as man advanced in civilization, and that while its traces are frequent in Neolithic times, they become very scarce or altogether disappear in the age of the mammoth and the reindeer.

As regards religious ideas they can only be inferred from the relics buried with the dead, and these are scarce and uncertain for the earlier periods. The caves in which Palæolithic man lived on the flesh of the Quaternary animals, have been so often used as burying-places in long-subsequent ages, that it is extremely difficult to ascertain whether the skeletons found in them are those of the original inhabitants. Thus the famous cave of Aurignac, in which Lartet thought he had discovered the tomb of men at whose funeral feasts mammoths and rhinoceroses were consumed, is now generally considered to be a Neolithic burying-place superimposed on an abandoned Palæolithic habitation.

There are not more than five or six well authenticated instances in which entire Palæolithic skeletons have been found under circumstances in which there is a fair presumption that they may have been interred after death, and these afford no clear proof of articles intended for use in a future life having been deposited with them. All we can say, therefore, is that from the commencement of the Neolithic period downwards, there is abundant proof that man had ideas of a future state of existence very similar to those of most of the savage tribes of the present day; such proof is wanting for the immensely longer Palæolithic period, and we are left to conjecture. The only arts which can with certainty be assigned to our earliest known ancestors are those of fire and of fashioning rude implements from stone by chipping. Everything beyond this is the product of gradual evolution.

CHAPTER VI.

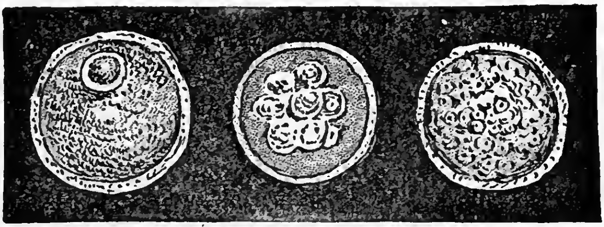
MAN'S PLACE IN NATURE.

ALTHOUGH the establishment of the great antiquity of the human race has attracted more immediate attention, being a fact at once intelligible to the general public, the researches of anatomists and physiologists, aided by the microscope, have brought to light results quite as remarkable as regards the individual man and his place in Nature. Until recently it was taken for granted that man was a special miraculous creation, altogether superior to and distinct from the rest of the animal world. This assumption, gratifying alike to our vanity and our laziness in the laborious search for truth, has been to a great extent disproved and replaced by the Law of Evolution.

The most striking proof of this is found when we trace scientifically the growth of each individual man from his first origin to his final development. Man, like all other animals, is born of an egg. The primitive egg, or ovum, which was the first germ of our existence, is a small cell about the one-hundredth of an inch in diameter, consisting of a mass of semi-fluid protoplasm enclosed in a membrane, and containing a small speck or nucleus of more condensed protoplasm. This nucleated cell is itself the first form into which a mass of simple jelly-like protoplasm is differentiated in the course of its evolution from its original uniform composition. The nucleated cell is the starting-point of all higher life, and by splitting up and multiplying repetitions of itself in geometrical progression, provides the cell material out of which all the complicated structures of living things are built up. In sexual generation, which prevails in all the higher forms of life, this process requires, in order to start it, the co-operation of two such cells or germs of life, one male, the other female.

HUMAN EGG.
Magnified 100 times.

The first remarkable fact is that the human egg is, at its commencement, undistinguishable from that of any other mammal, and remains so for a long period of its growth, going through its earlier stages of development in precisely the same way. At first the egg behaves exactly as any other single-celled organism, as for instance that of the amœba, which is considered the simplest form of organized life. It contracts in the middle and divides into two cells, each with its nucleus and each an exact counterpart of the original cell. These two subdivide into four, the four into eight, and so on, until at last a cluster of cells is formed which is called a *morula* from its resemblance to the fruit of the mulberry-tree. Development goes on, and the globular lump of cells changes into a globular bladder whose outside skin is built up of flattened cells. Then condensation takes place, from the more rapid growth of cells at particular points, and the foundation is laid of the actual body of the germ or embyro, the other cells of the germ-bladder serving only for its nutrition. Up to this point the germs not only of all mammals including man, but



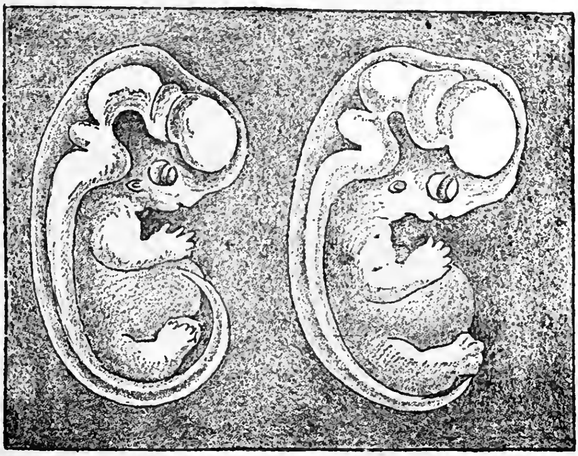
MAMMALIAN EGG.
First Stage. Second Stage. Third Stage.

of all vertebrate animals, birds, reptiles, and fishes, are scarcely distinguishable.

In the next stage the outer surface of the embyro develops three distinct layers, the outer one of which, or epidermis, becomes the outer skin; the inner one, or epithelium, the mucous membrane or lining of all the intestinal organs; and the intermediate layer the raw material of muscles, bones, and blood-vessels. The embyro is now contracted in the middle and assumes the form of a violin-shaped disc, and a slight longitudinal furrow appears, dividing it into two equal right and left parts, which is gradually converted into a tube containing the spinal marrow, to protect which a chain of bones or vertebræ is developed, forming the back-bone.

And now comes what is the most marvellous part of the process, viz., the development of the brain, eye, ear, and other organs of sense, from these simple elements. The brain begins as a swelling of the foremost end of the cylindrical marrow-tube. This divides itself into five bladders, lying one behind the other, from which the whole complicated structure of the brain and skull is subsequently developed.

The eye, ear, and other sense-organs, begin in the same way. A slight depression in the outer skin extends until the edges close and form a hollow space in which the eye is formed. At first it is a mere black pigment mark on the interior surface of the inclosed space, which develops into the retina, with a wonderful apparatus of optic nerves for conveying impressions photographed on it to the brain. The enclosed space itself is filled with a fluid, or vitreous humor, from which a lens is condensed for collecting the rays of light and concentrating them on the retina, and by degrees all the beautiful and complicated organs are evolved for perfecting the work of the eye and protecting it from injury. But this fact must be kept clearly in view: the process is identically the same as that by which the eyes of other animals are formed, and its various stages represent those by which the organs of vision have gradually risen to the development of a complete eye, in advancing from the lowest to the higher forms of life. Thus in the lowest, or Protista, the eye remains a simple pigment spot, which probably perceives light by being more sensitive to variations of temperature than the surrounding white cells. The next higher family develop a lens, and so on in ascending order, different families developing different contrivances for attaining the same object, but all starting from the same origin, development of the cells of the epidermis, and leading up to the same result, organs of vision adapted for the ordinary conditions of life of the creature which uses them. I say the *ordinary* conditions, for there are curious instances of the eye persisting, dwindling from disuse, and finally disappearing, in animals which live underground like the mole, or in subterranean waters like some fish in the Mammoth Cave of Kentucky and underground lakes of Carinthia, where the stimulus of light is no longer felt for many generations.



DOG (six weeks). MAN (eight weeks).
From Haeckel's "Schöpfungsgeschichte."

The history of the ear and other organs of sense is the same as that of the eye. They are all developments of the cell system of the outer skin, and all pass through stages of development identical with those at which it has been arrested in the progression from lower to higher forms of life. The same principles apply to the development of the inner organs, such as the heart, lungs, liver, etc., a striking illustration of which is found in the fact that the gill arches, or bones which support the gills by which fishes breathe, exist originally in man and all other vertebrate animals above the ranks of fish, but, in the development of the embryo, they are superseded by the air-breathing apparatus of lungs, and converted to other purposes in the formation of the jaws and organ of hearing. In fact, we may say that every human being passes through the stage of fish and reptile before arriving at that of mammal, and finally of man.

If we take him up at the more advanced stage, where the embryo has already passed the reptilian form, we find that for a considerable time the line of development remains the same as that of other mammalia. The rudimentary limbs are exactly similar, the five fingers and toes develop in the same way, and the resemblance after the first four weeks' growth between the embryo of a man and a dog is such that it is scarcely possible to distinguish them. Even at the age of eight weeks the embryo man is an animal with a tail, hardly to be distinguished from an embryo puppy.

As evolution proceeds the embryo emerges from the general mammalian type into the special order of *Primates* to which man belongs. This order, beginning with the lemur, rises through the monkey, the baboon, and tailed ape, up to the anthropoid apes, the chimpanzee, gorilla, and orang, which approach nearest to the human type. The succession is gradual from the lower to the higher forms up to the anthropoid apes, but a considerable gap occurs between these and man. It is true that in his physical structure man resembles these apes closely, every bone and muscle of the one having its counterpart in those of the other. But even at its birth the human infant is already specialized by considerable differences. The brain is larger, its convolutions more complex, the spine has a double curvature, adapting it for an erect posture, and the legs, with a corresponding object, are longer and stronger, while the arms are shorter and less adapted for climbing. The thumb also is longer, making the hand a better instrument for all purposes, except that of clasping the branches of trees, for which the long, slender fingers of the ape are more available. The great toe also is less flexible and the foot more adapted for giving the body a firm support and less for being used as a hand.

As growth proceeds after birth these differences become more and more accentuated. The infant chimpanzee is not so very unlike the infant negro, but after a certain age the sutures of the skull close in the former, making the skull a solid box, which prevents further expansion of the brain, and the growth of the bone is directed towards the lower part of the face, giving the animal a projecting muzzle, massive jaws, and a generally bestial appearance, while at the same time its intelligence is arrested and its ferocious instincts become more prominent. Still these higher apes remain creatures of very considerable intelligence and warm affections, as may be seen in the behavior of those which have been caught young and brought up under the influence of kind treatment. There is a chimpanzee now in the Zoölogical Gardens at Regent's Park, which can do all but speak, which understands almost every word the keeper says to it, and when told to sing will purse out its lips and make an attempt to utter connected notes. In the native state they form societies, obey a chief, and often show great sagacity in their manner of foraging for food and escaping from danger.

Even in lower grades of life than the anthropoid apes we can see plainly many of the germs of human faculties in an undeveloped state.

Those who are fond of dogs, and have lived much with them and understood their ways, must have been struck by the many human-like qualities they possess, and especially by the very great resemblance between young dogs and young children. They both like and dislike very much the same people and the same mode of treatment. They like those who take notice of them, caress them, talk to them, and, above all, those whom they can approach with perfect confidence of receiving uniform kind treatment. They dislike those who have no sympathy with them, or whose treatment of them is either cold or capricious. Their great delight is to play with one another, and often to tease and make a pretence of quarreling and fighting. They both have an instinct for mischief, and are constantly trying it on how far they can go without getting into serious difficulties.

Later in life, and in more serious matters, the dog has certainly the germs of intelligence, and does a number of things which require a certain exercise of reasoning power. He has a good memory, and imagination enough to be excited at the prospect of a walk where there is a chance of finding a rat or a rabbit, and to dream of chasing imaginary rabbits when he is lying curled up on the hearthrug. Every dog has an individual character of his own as clearly defined as that of an individual man, nor can the rudiments of consciousness be denied to the hound who, in a kennel of twenty others, knows perfectly well that he is Rover, and not Rattler or Ranger, and waits till his name is called to come forward for a biscuit. When he has got it, his sense of property makes him appropriate it as his own, and respect the biscuits appropriated to other dogs, at any rate to the extent of knowing perfectly well that he is doing wrong if he takes them by force or steals them.

In the moral qualities the dog approaches even more closely to man. His fidelity, affection, and devotion even to death, are proverbial. He feels shame and remorse when he has departed from the canine sense of right and wrong or from the canine standard of honor, and is happy when he feels that he has done his duty. What is this but the working of an elementary conscience? Even in the higher sphere of religious feeling, the dog feels unbounded love and reverence for the master who is the highest being conceivable to him, or in other words, his God; and he shudders as that master does in the presence of anything weird and supernatural. Every good ghost story begins by describing how the dogs howled and shrank to their master's feet when the first shadow of supernatural presence was cast on the haunted castle.

Capacity for progressive improvement can hardly be denied to a race which has developed such qualities from ancestors who, like the wild and half-wild dogs of Asia and America, had not even learned to bark, and were as unlike the civilized and affectionate collie, as Palæolithic man to his modern successor. In fact, the progress of the dog seems only to be limited by the want of organs of speech, and of an instrument like the hand by which to place himself in closer relation with the outer world.

The same remarks apply to the elephant, whose great sagacity seems clearly attributable to the possession of such an instrument in the trunk, inferior no doubt to the hand, but still very superior to the paw of the dog or to the hoof-enclosed fore-foot of the horse. In all animals the greater or less perfection of the instruments by which they act upon and are acted upon by the outer world, seems to be the principal factor in determining the quality of the brain as an organ of intelligence.

In the insect world we find still more wonderful exemplifications of the resemblance between animal and human intelligence. Ants live in organized societies, build cities, store up food for winter, keep aphides as milk-cows, carry on slave-hunting raids, and push the division of labor to such an extent that some tribes are all workers, others all warriors and slave-owners. These actions are not all merely mechanical and instinctive, for ants can to a considerable extent adapt themselves to circumstances, and alter their habits and mode of life when it becomes necessary in the "struggle for existence." The same is true of bees, beetles, and other insects, but it is useless to dwell on these, for the organization of the insect world is so different from that of the mammalian, to which man belongs, that no safe analogy can be drawn from one to the other. It is from the higher mammalian types that we can fairly draw the inference that, if like effects are produced by like causes, the more perfect intelligence, consciousness, and morality of man, must be the same in kind though higher in degree than the less perfect manifestations of the same qualities in animals of similar though less perfect physical organization.

There is one respect in which the human infant differs greatly from the young of other animals, viz., in the long period for which it remains in a condition of utter helplessness. In many of the lower forms of life the young creature emerges into the world with many of its necessary faculties complete, and has to learn comparatively little from education. The chicken runs about and picks up food on the day it escapes from the egg, and the young flycatcher will peck at flies with fragments of the shell still adhering to it. As we rise in the scale of creation, these instinctive aptitudes become fewer, and more time is required before the young animal can shift for itself; and at length, in the human infant, we arrive at a stage where for the first year or two it can do little to preserve its existence except to breathe and suck.

The reason of this is doubtless to be found in the higher development to which it is destined to attain. The faculties of every animal depend on two causes—first, heredity, or those which have been evolved from the type, and become fixed by succession through a long series of ancestors; secondly, adaptation, or those which are acquired by education, including in the term everything that is requisite to place the animal in harmony with its surrounding environment. The first are what are called instincts, which exist from the birth, and are preserved unconsciously and without an effort. The last involve an effort, and reference from the outer stations of the senses along the telegraph wires called nerves, to the central office of the brain, where the message is recorded and the reply considered and transmitted along another set of nerves to the muscles, where it translates itself into action. In either case the fundamental fact seems to resolve itself into a tendency of molecular motion to follow beaten rather than unknown paths. What the brain has once thought or perceived, it will think or perceive more readily a second time, and in like manner, a message which has once been transmitted and read off along a nerve, from muscle to brain or from brain to muscle, will be transmitted and read off more readily by practice, until at length it ceases to require conscious effort and becomes instinctive. We may see an illustration of this in the facility with which a piano player, who began by learning the notes with difficulty, acquires such aptitude that the execution of rapid passages becomes mechanical, and can be carried on without a mistake, even when the performer is thinking of something else or talking to a bystander.

The outer world with which every animal has to deal from its birth upwards, may be compared to a dense forest or jungle through which it has to find its way. A certain number of paths have been cut by its ancestors, and it finds them ready made by heredity; others it constructs for itself by repeated efforts until they become as broad and easy as those which it inherited; and finally, if the forest is thick and its area extensive it can only be explored by leaving the beaten paths of inherited or acquired instinct, and groping the way painfully by conscious effort and attention.

We can now see why the lower the animal, or in other words the less extensive the forest, the whole vital energy may be concentrated on the few beaten paths opened by heredity, and a few necessary actions may be performed from the first, instinctively and with great perfection, while in higher organisms the vital energy is employed in developing a great mass of future possibilities rather than a small number of inferior present realities. The baby cannot run about the room and feed itself like the chicken, because the baby has to grow into a man or woman, while the chicken has only to grow into a fowl which can do very little more in its adult than in its infant state.

In fact, when we come to analyze the sum of faculties of the adult man, we find that they are derived to a surprisingly small extent from heredity as compared with education. In saying this, however, it must be understood that the term "heredity" is limited to that direct heredity which transmits characters by instinctive necessity, and not to the far larger sphere of indirect heredity by which faculties, arts, modes of thought, and rules of conduct, are accumulated in civilized societies, and become the principal instrument of education in its larger sense. If it were possible to suppose a human infant born of civilized parents, left entirely to itself, what would it grow into? Perhaps it would learn to walk, though this is not quite certain, as the few wild children who have been discovered in forests, went very much on all fours, and if we can believe the accounts of wolf children in India, those educated among wolves adopt their gait and habits; certainly it would not learn to speak, in the sense of using any articulate language; its arts would not extend beyond recognizing a few articles of food, and perhaps using stones to crack nuts, and constructing some rude shelter from branches of trees. It would know nothing of fire, and on the whole would not be so far advanced as its oldest Palæolithic ancestor.

As regards a moral sense, and all that we are accustomed to think the highest attributes of humanity, it is clear that his mind would be a blank. Even at a much more advanced stage, such ideas evidently come from education, and are not the results either of inherited instinct or of supernatural gift. An English child kidnapped at an early age by Apache Indians or head-hunting Dyaks, would, to a certainty, consider murder one of the fine arts, and the slaughter of an inoffensive stranger, especially if accomplished with a treachery that made the exploit one of little risk, an achievement of the highest manhood. If brought up among Mahometans he would consider polygamy, if among the Todas polyandry, as the natural and proper relation of the sexes. All that can be said is, that if recaptured and brought back to civilized society, he would perhaps be assisted by heredity in adopting its ideas more readily than would be the case if he had been born a savage.

It is clear, therefore, that the history of the individual man tells the same story of evolution from low beginnings as is told by that of the human race as traced from Palæolithic, through Neolithic, into modern times. His law is progress, worked out by conscious effort called forth by the environment of outward circumstances, and accelerated from time to time by the successful efforts of a few superior men, whose greater sum of energy or happier organization for development, enables them to pioneer new paths through the vast unexplored forests of science, art, and morality.

The difficulty of accounting for the development of intellect and morality by evolution is not so great as that presented by the difference in physical structure between man and the highest animal. Given a being with man's brain and man's hand and erect stature, it is easy to see how intelligence must have been gradually evolved, and rules of conduct best adapted for his own good and that of the society in which he lived must have been formed and fixed by successive generations, according to the Darwinian laws of the "struggle for life" and the "survival of the fittest."

But it is not so easy to see how this difference of physical structure arose, and how a being came into existence which had such a brain and hand, and such undeveloped capabilities for an almost unlimited progress. The difficulty is this: the difference in structure between the lowest existing race of man and the highest existing ape is too great to admit of the possibility of one being the direct descendant of the other. The negro in some respects makes a slight approximation towards the Simian type. His skull is narrower, his brain less capacious, his muzzle more projecting, his arm longer than those of the average European man. Still he is essentially a man, and separated by a wide gulf from the chimpanzee or gorilla. Even the idiot or *crétin*, whose brain is no larger and intelligence no greater than that of the chimpanzee, is an arrested man and not an ape.

If, therefore, the Darwinian theory holds good in the case of man and ape, we must go back to some common ancestor from whom both may have originated by pursuing different lines of development. But to establish this as a *fact* and not a *theory* we require to find that ancestral form, or, at any rate, some intermediate forms tending towards it. We require to find fossil remains proving for the genus man what the Hipparion and Anchitherium have proved for the genus horse, that is, gradual progressive specialization from a simple ancestral type to more complex existing forms. In other words, we require to discover the "missing link." Now it must be admitted that hitherto, not only have no such missing links been discovered, but the oldest known human skulls and skeletons, which date from the Glacial period, and are probably at least 100,000 years old, show no very decided approximation towards any such pre-human type. On the contrary, one of the oldest types, that of the man of the sepulchral cave of Cro-Magnon, is that of a fine race, tall in stature, large in brain, and on the whole superior to many of the existing races of mankind. The reply of course is that the time is insufficient, and if man and the ape had a common ancestor, that as a highly developed anthropoid ape certainly, and man probably, already existed in the Miocene period, such ancestor must be sought still further back, at a distance compared with which the whole Quaternary period sinks into insignificance. It is said also that the discovery of man's antiquity is of quite recent date, and that thirty years ago the same negative evidence was quoted as conclusive against his existence in times and places which now afford his remains by tens of thousands. All this is true, and it may well make us hesitate before we admit that man, whose structure is so analogous to that of the animal creation, whose embryonic growth is so strictly accordant with that of other mammals, and whose higher faculties of intelligence and morality are so clearly not miraculous instincts but the products of evolution and education, is alone an exception to the general law of the universe, and is the creature of a special creation.

This is the more difficult to believe, as the ape family which man so closely resembles in physical structure, contains numerous branches which graduate into one another, but the extremes of which differ more widely than man does from the highest of the ape series. If a special creation is required for man, must there not have been special creations for the chimpanzee, the gorilla, the orang, and for at least 100 different species of apes and monkeys which are all built on the same lines?

What are the facts really known to us as to man, his nature, and his origin?

Man is one of a species of which there are in round numbers some 1,200 millions of individuals living at the present time on the earth. Taking thirty years as the average duration of each generation there are thus over 3,000 millions who are born and die per century, and this has gone on more or less during the period embraced by history which extends for a great part of the Old World over thirty centuries, in the case of Assyria and China over forty or fifty, and in Egypt over seventy centuries. At the commencement of these historical periods population was dense, probably in Egypt and Western Asia denser than at present, and civilization far advanced. The Pyramids, which are at the same time the oldest and the largest buildings in the world, prove this conclusively, both from the mechanical skill and astronomical science shown in their construction, and from the great accumulation of capital and highly artificial arrangements of society which could alone have rendered such works possible. The great mass of the population in these olden times lived in what is known as the Old World, and was accumulated mainly in the great valley systems of the Nile, and of the various rivers and irrigated plains of the southern half of the continent of Asia. Northern Asia and Europe were thinly inhabited by ruder tribes. Of America and the interior of Africa we know little until a much later date, but the populatian was in all probability sparse and savage, while in Australia, if it existed at all, it was still scantier and more savage; while in New Zealand and most of the Pacific Islands it has only been introduced by migration within comparatively recent times.

The next leading fact we have to observe is that the human race is not everywhere the same, but is divided into several well-marked varieties. The most obvious distinction is that of color. In the Old

World there are three distinct and clearly characterized groups—the white, the yellow, and the black. These are found mainly in three separate zoölogical provinces: the white in the temperate and north-temperate zones of Europe and Western Asia, the yellow in those of Eastern Asia, and the black in the tropical zone, principally of Central Africa. Where they are pure and unmixed, these race-types differ from one another not in color only but in many other important and permanent characters. The average size of the brain, the complexity of its convolutions, the shape of the skull, the bones of the face and jaws, the comparative length of the limbs, the structure of the hair and skin, the characteristic odor, the susceptibilities to various diseases, are all essentially different, so that no observant naturalist, or even observant child or dog, could ever mistake a Chinaman for a Negro, or a Negro for an Englishman.

Such a naturalist, seeing for the first time typical specimens of the three races, would pronounce them without hesitation to be distinct species, and would predict with much confidence that they would either not cross, or, if they did, would produce a hybrid progeny of inferior fertility.

But here he would be wrong, for, in fact, the most opposite races breed freely together, and produce a fertile progeny.

Moreover, when we extend our view beyond the clearly distinguished types of the white, yellow, and black, as seen in Caucasian, Mongoloid, and Negro races, we find these types breaking off into sub-types and shading off towards each other, while a large proportion of the human race consists of brown, red, olive, and copper-colored people, who may either be original varieties, or descended from crosses between the primitive races. Small isolated groups also crop up, differing from the main races, of whom it is hard to say from whom they are descended or how they got there; as for instance the Hottentots, in South Africa, the pigmy black Negritos of the Andamans and other South Asiatic islands, the Papuans and Australians, the hairy Ainos of Japan, and some of the aboriginal races of India.

To a certain extent climate seems to have had an influence in creating or developing the main typical differences. Thus the main line of black races lies along the hot tropical belt of the earth from Old to New Guinea. But the rule is not universal, there is no similar type in tropical America, where a singular uniformity of type and color prevails throughout the whole continent. Even in Africa we find the Negro type, while retaining its black color, shading off towards higher types and losing its more animal-like characteristics. Again, while color becomes generally lighter as we pass from tropical to south-temperate and from south to north-temperate regions, if we go still further north we find darker races, such as the Lapps and Esquimaux, and in one remarkable instance the color within the temperate zone itself actually becomes darker with increase of latitude, and the aboriginal savage of Tasmania, in a climate like that of Devonshire, was blacker than many negroes.

Even within great and well-defined races themselves there are clearly marked varieties. Thus the white race consists of the two distinct types of the fair-whites and dark-whites, the former prevailing in Northern Europe and the latter in Southern Europe, Western Asia, and North Africa; the contrast between a fair Swede with flaxen hair and blue eyes, and a swarthy Spaniard with black hair and eyes, being almost as marked as between the latter and some of the higher black or brown races. Throughout a great part of Europe, including specially England, it is evident that the existing population is derived mainly from repeated crosses of these two races with one another and probably with earlier races.

In the existing state of things also it is evident that if the different races of mankind ever really did pass into one another under influences like those of climate, the time of their doing so is long past. A colony of English families transported to tropical Africa would to a certainty die out long before they had taken even the first step towards acquiring the black velvety skin, the woolly hair, the projecting muzzle, and the long narrow skull of the typical Negro, while a Negro colony transported to Scotland or Scandinavia would as certainly disappear from diseases of the chest and lungs, long before they began to vary towards the European type. The yellow race seems to be on the whole the best fitted to withstand climate and other external influences, and it certainly shows no signs anywhere of passing over either into the Caucasian or the Negro type.

On the whole, therefore, if the fact of fertile inter-crossing is to be taken as proving the unity of the human race and their probable descent from a common ancestor, and we are to assume that all the great varieties which we find existing are the result of modifications gradually introduced by climate and surrounding circumstances, it is evident that the point of divergence must be put at an immense distance.

This is the more certain, as when we look back for a period of more then 4,000 years, we find from the Egyptian monuments that some of the best-marked existing types have undergone no sensible change. The portraits of negroes and of Semitic dark-whites painted on the walls of temples and tombs of the 12th dynasty, about 2,000 B.C., might be taken as characteristic portraits of the negro and Jew of the present day, and the modern Egyptian fellah reproduces with little or no change the features of the Ancient Egyptians of the days of Rameses and Amenophis. It is evident, therefore, that where no great change has taken place from crossing of races, they will maintain their special characters unaltered for more than 100 generations. Indeed we might say for 200 generations, for the statues and wooden statuettes from the tombs of Sakkara, the ancient Memphis, which certainly date back for more than 5,000 years, show us the Egyptian type in its highest perfection, and with a more intellectual and I might say modern expression than is found 1,000 or 2,000 years later, when the type of the higher classes had evidently deteriorated somewhat from a slight infusion of African elements.

The same conclusion of the great distance at which any common point of divergence of the various races of mankind must be placed, is confirmed by a totally different line of inquiry, that into the origin of language.

Philologists have clearly proved that languages did not spring into existence ready made, like Minerva from the brain of Jupiter, but have followed the general law of Nature, and have had their periods of birth, growth, and evolution from simple into complex organism. Now there is a vast variety of languages, some say more than a thousand. A large proportion of these are, of course, only what may be called dialects of the same original language, as in the case of the whole Indo-European family, including Sanscrit, Zend, Greek, Latin, Teutonic, Celtic, and Slavonic, with all their offshoots and derived branches, as well as many others. These can be all traced back to the common root of the primitive language of an Aryan white race, who radiated by successive migrations from some region in the elevated plateaux of Central Asia. Any one who wants to be convinced of this has only to refer to Max Müller's works and trace the history of one verb, viz., that used to denote individual existence.

Asmi in Sanscrit has become *eimi* in Greek, *sum* in Latin (whence *sono, suis*, and all the modern derivatives of Latin races), and "am" in English; while the Latin *est*, the Greek *esti*, and the German *ist*, are clearly akin to the original *asti*. It may help in understanding how language has been formed if we point out that "I am" originally meant "I breathe," and "he is" is the more general and abstract form of "he stands."

But there are a number of languages between which no such relationship can be traced, which are constructed on radically different principles, and have no resemblance with one another in their roots, or primitive sounds used to express objects and simple ideas, except in the few cases where it can be traced to importation from abroad, or to imitation of naturally suggested sounds, such as those which have led so many nations to express the idea of "mother" by a sound resembling the bleating of a lamb. Obviously, similarity of sound in such words as are used for the ideas of father, mother, cow, crow, thunder, crack, splash, and so on, suggests no common origin, and as most, or at any rate a great many roots, were probably derived originally in this manner, though long since diverted to express other ideas by associations which it is impossible to trace, the wonder rather is that we should find so many languages with so few roots in common. The best authorities tell us that a list of fifty to one hundred languages could be made of which no one has been satisfactorily shown to be related to any other.

The main distinction between languages, however, is to be found in their inner mechanism, or grammar, rather than in the mere difference of root-sounds. The result of years of mechanical training in barbarous Latin and Greek grammars in our English public schools has been to leave the average Englishman completely ignorant of the real meaning of the word "grammar," and almost incapable of comprehending that it can mean anything else than a string of arbitrary rules to be learned by heart for the vexation of small boys.

And yet grammar is really most interesting, as showing the modes by which the dawning human intellect has proceeded, at remote periods and among different races, in working out the great problem of articulate speech, by which man rises into the higher regions of thought and is mainly distinguished from the brute creation. Consider first what the problem is, and then some of the principal modes which have been invented to solve it.

Suppose some primitive race to have accumulated a certain stock of root-words, or simple sounds to signify definite objects and simple ideas, they must soon find that these alone are not sufficient to convey briefly and clearly to other minds the ideas which they wish to express. For instance, suppose a tribe had got root-words to express the ideas of "man," "bear," and "kill." What one of the tribe wants to convey from his own mind to that of his neighbor may be, "The man has killed the bear," or "The bear has killed the man," or "The" (or "A) man has killed a bear," or "bears," or "will" or "may have" killed, and so on through a vast number of variations on the original three-note theme. Up to a certain point, a man might succeed in making himself understood by using his three root-sounds in a certain order, aided by the pantomime of accent and gesture; and the Chinese, though one of the oldest civilized peoples of the world, have scarcely got beyond this stage. But the process would be difficult and uncertain, and at length it would occur to some genius that such modifications as those of definite and indefinite, past and present, singular and plural, etc., were of general application, not to the particular three or four roots which he wished to connect, but to all roots. The next step would be to invent a set of sounds which, attached in some way to the root-sounds, should convey to the hearer the sense in which it was intended that he should take them.

This is the fundamental idea of grammar, but it has been worked out by different races in the most different manner. The Chinese and other allied races in the South-east of Asia, such as the Burmese and Siamese, have solved it in the simplest manner. Their languages are what is called monosyllabic—that is, each word consists of a single syllable, and is a root expressing the fundamental idea, without distinction of noun from verb, active from passive, or other modifications. They have to trust, therefore, to express their meaning, mainly to syntax, or the order in which words succeed one another, which, up to a certain point, is the simplest method, and is largely adopted in modern English. Thus, "Man kill bear," "Bear kill man," convey the meaning just as clearly as the classical languages do by cases, when they distinguish whether the man is the killer or the killed by saying *homo* or *hominem*. But the monosyllabic system limits the nations who use it to an inconveniently small number of words, and fails in expressing their more complex relations, so that we find the same word in Chinese or Siamese often expressing the most different ideas, and the meaning can only be conveyed by supplementing the root-words and syntax by accent and other conventional signs which are akin to the primitive devices of gesture language. Thus, in Siamese, the syllable *ha*, according to the note in which it is intoned, may mean a pestilence, the number five, or the verb "to seek."

This very primitive and almost infantine form of language is confined to one family, that of the Chinese and Indo-Chinese, who, it may be observed, are by no means simple or primitive in other respects, but stand and have stood for centuries at a comparatively high level of civilization. All other races, including the most savage, have adopted some form or other of grammar, *i.e.*, of modifying original root-sounds by additional generic sounds of definite determination; but the devices on which they have hit for this purpose are most various. Thus, the grammar of the Aryan family of languages has been formed by reasoning out such general categories of thought as articles, pronouns, and prepositions, coining sounds for them and prefixing these sounds to the root-sounds as separate determinating signs. More complex shades of meaning are conveyed principally by inflections, *i.e.*, by adding certain generic new sounds to the the original root-word, and incorporating them with it so as to form modifications which are a sort of secondary words. Thus the ideas of present, past, and future love, loving, and being loved, lovely, and so on, are formed by transforming the root *amo* into such modifications as *amor*, *amavi*, *amabo*, *amans*, *amabilis*, etc. We can see this process in the course of formation in the change which converted the old English form "Cæsar his" into the modern genitive "Cæsar's."

Other families again obtain the same results by very different processes. The Semitic languages, for instance, including Hebrew, Arabic, Assyrian, and Phœnician, are what is called "triliteral," *i.e.* they consist of roots mostly of three consonants, and express different shades of grammatical meaning by altering the internal vowels. Thus from the root m-l-k are derived *melek*, a king; *malak*, he reigned, and so on.

The Turanian family, comprising Huns, Turks, Finns, Lapps, and other Mongolian races of Northern Asia, all speak agglutinative languages, *i.e.*, languages in which the root is put first and is followed by suffixes strung on to it, but not incorporated with it and remaining distinct. Thus in Turkish, the root *sev*, to love, is expanded into *sevishdirilmedeler*, meaning "incapable of being brought to love one another."

These are only given as specimens of some of the most marked of the vast varieties of language which have been examined and classified by philologists. They suggest a great many interesting reflections, but I confine myself to those which bear more immediately on the subject of man's origin and development. It is evident that they imply great antiquity for the existence, not of man only, but of separate races of men speaking separate languages.

Babylonian inscriptions, quite 4,000 years old, show that the characteristic features of the Aryan and Semitic languages were as clearly established then as they are now; and the hieroglyphics of Egyptian monuments, 1,000 years older, show the Coptic language essentially the same as modern Coptic, and although presenting some points of analogy with Semitic, too different to be classed with it. If these are descended from a common ancestor, clearly their origin must be extremely remote. And even with unlimited time it is difficult to conceive how such radical differences in the structure of languages could have arisen unless the different races had branched off before any clear form of articulate speech had become fixed. Could a race accustomed for generations to the free-flowing inflectional Aryan, have deserted it for the cramped forms of the Semitic, or *vice versâ*, could the Semite have adopted the modes of thought and expression of Sanscrit? And the same difficulty would apply in at least twenty or thirty cases of other families of language.

It must be recollected that language is not merely the conventional instrument of thought, but to a great extent its creator, and the mould in which it is cast. The mould may be broken, and races abandon old and adopt new languages by force of external circumstances, such as conquest or contact with and absorption by superior races, but there is no instance of its being so transformed from within as to pass into a totally different type. Nor can we very well see how root-words once attached to fundamental ideas, such for instance as the simpler numerals, should come to be forgotten and new and totally different words invented.

Of course, the explanation was easy in the olden days, when everything was referred to miracle. Languages were different because God had made them so, to baffle the attempt of united mankind to build a tower high enough to reach to heaven. But the theory of special miraculous creation for each language cannot stand a moment's investigation.

As in the case of the animal world, special creations, if admitted at all, must be multiplied to an extent which becomes absurd. Is every petty tribe of savages who speak a language unintelligible to others to be supposed to have had it conferred upon it as a miraculous gift? Was the language of the extinct Brazilian tribe, of which Humboldt tells us that a very old parrot spoke the last surviving words, one of the languages used to scatter the builders of the Tower of Babel? Or, still more conclusively, where we know and can prove that one part of a language is the product of natural laws, can we assume that another part of the same language is the result of miracle? Did it require Divine inspiration to make the old Egyptians call a cat *miaou*, or to teach so many nations to express the idea of mother by imitating the bleating of a lamb? If not, why should half the words in a dictionary be miraculous and half natural?

And if Cæsar is correctly reported to have been more proud of discovering a new case than of conquering Gaul, ought we not to "render unto Cæsar the things that are Cæsar's," and assign grammar as well as words to human invention? In short, no reasonable man who studies the subject can doubt that language is just as much a machine of human invention for communicating thought, as the spinning jenny is for spinning cotton.

The general conclusion, then, to be drawn from the study of language points in the same direction as that of all other branches of science, viz., that their true history is that of evolution from simple origins by the operation of natural laws over long periods of time into forms of greater complexity and higher development. What language really does for us is to take up the thread where the oldest history fails us, and show that even at this date it is impossible to doubt that the human race must have been already in existence for a very long period, and in existence as at the present day in several sharply distinguished varieties, so that the common origin, if there be one, must be placed still further back. As history verified by the Egyptian monuments extends over a period of nearly 7,000 years, this is equivalent to saying that such a period can only be a very small part of the total time which has elapsed since man became an inhabitant of the earth.

The origin and development of religions have been much discussed, but too often with a desire to make theories square with wishes. The subject also does not admit of such precise determination as in treating of arts and languages, which have left traces of themselves in the form of primitive implements and primitive roots.

The history of religions really begins with written records, or at the earliest with the older myths which are embodied in these records. But these are all comparatively modern, and imply a considerable progress in civilization before they could have existed. If we wish to form some idea of what may have been the primitive elements from which religion was evolved, during the long Neolithic and still longer Palæolithic periods which preceded history, we must look at what are actually the religious ideas of contemporary savage and semi-barbarous races.

At the very lowest stage of savagery we find races like the Australians, the Bushmen, the Mincopies, and the Fuegians, who cannot be said to have any religion at all, or at the most some vague ideas of ghosts and spirits. The Mincopies of the Andaman Islands, who are considered by Professor Owen as "perhaps the most primitive, or lowest in the scale of civilization, of the human race," are reported by Dr. Mowatt to have "no idea of a Supreme Being, no religion, nor any belief in a future state of existence." Sir J. Lubbock says of the Australians that "they have no religion, nor any idea of prayer; but most of them believe in evil spirits, and all have great dread of witchcraft."

As we rise above this level of the lowest savagery we find ideas of religion beginning to grow from two main tap-roots. The first is the idea of ghosts or spirits, which arises naturally from dreams and visions and develops itself into ancestor and hero-worship, and belief in a world of spirits, good and evil, influencing men's lives and fortunes, and in many forms of sickness taking possession of their bodies. This spirit-worship also necessarily leads to some dim perception of a future life.

The other tap-root is the inevitable disposition to account for the phenomena of nature, when men first began to reflect on them, by the agency of invisible beings like themselves; in other words, of anthropomorphic gods. This is a higher and later stage of religious belief than the former, for it implies a certain disposition to inquire into the causes of things and a certain amount of reasoning power to infer like causes from like results.

But the two often blend together, as in the religions of the Aryan race, in which we see deified heroes and ancestors crowding the courts of Olympus, with a multitude of anthropomorphic gods, who are often merely obvious personifications of natural phenomena or astronomical myths. Thus Varuna, Ouranos, or Uranus, are personifications of the vault of heaven; Phœbus, the shining one, of the sun; Aurora, of the dawn; while Hercules is half deified hero and half solar myth. Sometimes, however, of the two stems of religion one only has flourished, and the other has either never existed, or been overshadowed by the first and relegated to a lower sphere. Thus the great Chinese civilization, comprising such a large portion of the human race, has apparently developed its religion entirely from the idea of spirits and spirit-worship. The worship of ancestors is its main feature, and its sacred books are, in effect, treatises on ethics and political economy, with rules for rites and ceremonies to enforce decent and decorous behavior, rather than what we should call works of religion. There is no trace of a conception of anthropomorphic gods in the genuine national Chinese religion from Confucius downwards; and even the introduction of Buddhism has done little but add the deified hero, Buddha, to the list of divine ancestors and give more definite shape to various vague superstitions. In like manner the whole Buddhist world can hardly be said to recognize anything beyond their incarnate hero, except a Nirvana or metaphysical abstraction, rather than a personal deity.

With other races again, and specially the Hebrew, the idea of a tribal anthropomorphic God has gradually swallowed up that of other gods, developed into that of one Almighty Being, and dwarfed that of ghosts and spirits. The primitive Hebrews, indeed, carried this so far as to exclude all ideas of a future life from their religious system.

Their primitive God, however, was strictly anthropomorphic, and modelled on the idea of an Oriental sultan—sometimes good and beneficent, but sometimes cruel and capricious, and above all jealous of any disrespect and enraged by any disobedience. Morality seems at first to have had little or nothing to do with these conceptions, and there is not the remotest trace in the early history of any religion, of its having been born ready-made from the necessary intuition of one Almighty God of love, mercy, and justice, which is so confidently assumed by many metaphysicians and theologians. On the contrary, conscience had to be first evolved, and the process may be followed step by step by which, as manners became milder and ideas purer, the grosser attributes of Deity were gradually purged off, and the idea of a just and merciful God was evolved from barbaric elements.

These considerations, however, lead us far from the question of the first dawn of religion among primitive man. Judging from the earliest facts of history, and the analogy of modern savage races, where we might look for the first traces of religious ideas would be from the contents of tombs and from idols. When a tribe had attained to some definite idea of a future life it would almost certainly bury weapons and implements with its dead, as is the case with modern savages. When it had reached the stage of worshipping anthropomorphic deities, it would probably frame images of them, some of which would be found in their tombs and dwellings.

The latter test soon fails us. In the early Egyptian tombs, and in the remains of the prehistoric cities excavated by Dr. Schliemann, images of owl and ox-headed goddesses, and other symbolical figures or idols, are found in abundance. But when we ascend into Neolithic times, such idols are no longer found, or, if found, it is so rarely that archæologists still dispute as to their existence. Certain crescents found in the Swiss lake-dwellings were at one time thought to indicate a worship of the moon, but the better opinion seems to be that they were used as rests for the head during sleep, as we find similar objects now used in many parts of the world. Among the many thousand objects recovered from these Swiss lake-dwellings and other Neolithic abodes, there are only a very few which may possibly have been rude idols or amulets, and the only ones which may be said with some certainty to have been idols, are one or two discovered by Mons. de Braye in some artificial caves of the Neolithic period, excavated in the chalk of Champagne, which appear to be intended for female figures of life size with heads somewhat resembling that of the owl-headed Minerva.

When we pass to Palæolithic times the evidence of idols becomes more faint, and rests solely on the conjecture that some of the figures carved by the Reindeer-men of La Madeleine and other caves, may probably have been intended for amulets. As they were such skilful carvers, and so fond of drawing whatever impressed itself on their imagination, the presumption is strong that they had not advanced to the stage when the worship of gods symbolized by idols had come into existence, as otherwise more undoubted idols must have been found in the caves which were so long their habitations, and which have yielded such a number of remains of works of art.

The evidence for a belief in a future existence and in spirits is more conclusive. Throughout the whole Neolithic period we find objects buried with the dead which were evidently intended for use in a future life. We find also in many Neolithic tombs a singular fact which points to the existence of a very long belief in evil spirits. Many of the skulls, especially of young people, have been trepanned, that is, a piece of the skull has been cut out, making a hole, apparently to let out the evil spirit which was supposed to be causing epilepsy or convulsions; and where the patient had recovered and the wound healed, when he died long afterwards, a piece of the skull, including this trepanned portion, was sometimes cut out and used apparently as an amulet. The objects deposited in graves show that the idea of a future life was, as with most savages of the present day, that of a continuation of the same life as he had led here, though perhaps in happier hunting-grounds. In some cases a great chief seems to have had wives and slaves slaughtered and buried with him, though the proofs of this are more clear and abundant in later prehistoric times than during the Neolithic period. Cannibalism, however, seems to have occasionally prevailed both in Palæolithic, Neolithic, and prehistoric times, as it did so extensively among modern savage races before they came under civilizing influences. This is clearly proved by the number of human bones, chiefly of women and young persons, which have been found charred by fire and split open for extraction of the marrow.

The evidence of belief in a future life becomes more rare and uncertain in Palæolithic times. Perhaps it may be because we have so few authentic discoveries of Palæolithic burying-places, and so many instances of caves, once inhabited by Palæolithic races, being used long afterwards as Neolithic sepulchres. After the famous cave of Aurignac it is difficult to trust any evidence of the discovery of a real Palæolithic sepulchre which has not been subsequently disturbed.

In the few cases also where Palæolithic skeletons have been found, as in that of the men of Neanderthal and Mentone, they have often been those of single individuals, and it may be doubted whether they were buried there, or merely died in the caves in which they lived, in which case any implements found with them do not necessarily imply that they were placed there for use in a future life. On the whole it seems doubtful whether any certain proofs of burials denoting knowledge of a future life can be found in Palæolithic times, and if there are, they are certainly few and far between, and confined to the later stages of that period.

All we can say is, that religion certainly did not descend ready-made among these aboriginal savages, but that, like language, it was slowly developed from beginnings as rude as those we now find among the lowest races of savages.

It may be well, however, to say here, once for all, what is applicable to many other passages in this book, that the question of the origin of any religion is entirely different from that of its truth or falsehood. To explain a thing is not to disprove it; on the contrary, a thing only really becomes true to us when we understand it. A stately oak, with wide-spreading branches, that give shade and shelter to the cattle of the fields, is not the less a fact because we know that it did not drop ready-made from heaven, but grew from an acorn. The intrinsic truth of a religion must be tested by the conformity which, in a given stage of its evolution, it bears to the facts of the universe as disclosed by science, and to the feelings and moral perceptions which have been equally developed by evolution in the contemporary world.

All I contend for is, that all religions have grown and been developed from humble origins, and that their history, impartially considered, does not contradict, but on the contrary greatly confirms the law of natural evolution.

Of the two faculties by which man is commonly distinguished from the brute creation, viz., that of being the speaking and the tool-making animal, the former attribute has been shown to be the product of evolution from origins long since lost in the far-off distance of remote ages.

The same remark is even more certainly true as regards the other attribute of tool-making, or, in its widest sense, adapting natural laws and natural objects to the arts of life by intelligent application. The primitive roots, so to speak, of this industrial language, which in the case of spoken language for the most part elude our search, are here furnished by the Palæolithic remains found so abundantly in river drifts and caves. There can be no doubt whatever that the modern wood-cutter's axe and carpenter's adze are the lineal descendants of the rudely-chipped *hâches*, or celts, which are dug out of the gravels of St. Acheul, or from below the stalagmite of Kent's Cavern. The regular progression can be traced from the mass of flint rudely chipped to a point, with a butt-end left rough to grasp in the hand, up to more symmetrical and carefully-chipped forms; to implements intended to be hafted or fastened to a handle; to implements ground and polished to a sharp edge and pierced for the handle; and finally to the finished specimens of the later Neolithic period, which exactly represent the adze and battle-axe, and are almost identical with those used quite recently by the Polynesians and other semi-civilized races who had no access to metals. From these the transition to metals is easily traced. the first bronze implements and weapons being facsimiles of those of polished stone which they superseded, and the gradual development of bronze, and from bronze to the cheaper and more generally useful metal, iron, being a matter of quite modern history.

In like manner, the development of the knife, sword, and all cutting instruments, from the primitive flint flake, can be traced step by step, and is beyond doubt; and equally so the development of all missils, from the primitive chipped flint, used as a javelin or arrow-head, up to the modern rifle. When we catch the first glimpes of the beginnings of human art or industry, the furniture or stock-in-trade of Palæolithic man appears to have been as follows:

He was acquainted with fire. This seems to be clearly established by the charred bones, charcoal, and other traces of fire which are found in the oldest Palæolithic caves, and even in the far distant Miocene period, if we can believe in the flints discovered by the Abbé Bourgeois in the strata of Thenay, some of which appear to have been split by the action of fire. This is a remarkable fact, for a knowledge of the means of kindling fire is by no means a very simple or obvious attainment. Apes and monkeys will sit before a fire and enjoy its warmth, but no monkey has yet developed intelligence enough even to put fresh sticks on to keep up the fire, much less to rekindle it when extinct. Primeval man must often have had experience of fire from natural causes, as from forests and prairies scorched by a tropical sun being set on fire by lightning, or from volcanic eruptions; but how he learned from these to kindle fire for himself is not so obvious. Savage races, as a rule, do so by converting mechanical energy into heat, by the friction of a stick twirled round in a hole, or rubbed backwards and forwards in a groove in another piece of wood; and there are old observances among civilized nations which show that this was the mode practiced by their ancestors, as when the sacred fire in the Temple of Vesta was relighted in this manner by the old Romans if it had chanced to be extinguished. It is probable, therefore, that this was the original mode of obtaining fire, but if so, it must have required a good deal of intelligence and observation, for the discovery is by no means an obvious one, nor is it easy to see any natural process that might suggest it.

Neither ancient history nor the accounts of existing savage races throw much light on the question. The narratives of the discovery of fire contained in the oldest records are obviously mythical, like the fable of Prometheus, which is itself a version of the older Vedic myth of the god Agni (whence the Latin *ignis* or fire) having been taken from a casket and given to the first man, Manou, by Pramantha, which in the old Vedic language means taking forcibly by means of friction. Of the same character are the mythical legends of savage races of fire having been first brought by some wonderful bird or animal; and there is nowhere anything like an authentic tradition of the fact of its first introduction. There have been reports of savages who were unacquainted with fire, but they have never been well authenticated, and the nearest approach to such a state of things was probably furnished by the aborigines of Van Diemen's Land, of whom it is said that in all their wanderings they were particularly careful to bear in their hands the materials for kindling a fire, in the shape of a firebrand, which it was the duty of the women to carry, and to keep carefully refreshed from time to time as it became dull.

On the whole, traditions all point to fire having been first obtained from friction, and it is possible that the first idea may have been derived from the boughs of trees, or silicious stalks of bamboos, having been set on fire when rubbed together by the action of the wind.

It is easier to see the origin of the remaining equipment of primitive man, viz., chipped stones, for flints splintered by frost or fire often take naturally the forms of sharp-edged flakes and rude hatchets or hammers, and very little invention was required to improve these specimens, or endeavor to imitate them by artificial chippings. It is rather surprising that this art did not improve more rapidly, for it is evident that the old Palæolithic period must have lasted a long time before any decided progress began to show itself. And during this long period a singular uniformity appears to have prevailed throughout the Palæolithic world. The rude form of the celt or *hâche*, with a blunt butt and chipped roughly to a point, is found in the oldest river gravels and caves wherever they have been investigated, and the forms of the Somme and the Thames are repeated in the quartzite implements of the Madras laterite.

In the very oldest caves and river deposits the tool-equipment of man seems to have been very much limited to these rude celts, used probably for smashing skulls in war and the chase, and splitting bones to get at the marrow; sharp-edged flakes for cutting; rude javelin-heads; and stones chipped to a rounded edge, very like those used by the Esquimaux for scraping bones and skins. As we ascend in time we find arrow-heads of stone and bone, at first unbarbed and gradually becoming barbed, showing that the bow had been discovered; harpoons of bone and fish-hooks; bone pins and needles; and a much greater variety and more carefully-chipped forms of flint tools and weapons; until we finally reach the upper reindeer stage of caves like that of La Madeleine, where artistic drawings and carvings are found, and the equipment generally is superior to that of many existing savage tribes, and not much inferior to that of the Esquimaux and other Arctic races.

We then pass into Neolithic times, when many of the chief elements of civilization are already in full force. Man has emerged in many localities from the hunter into the pastoral stage, the principal domestic animals are known, and in some of the later lake-dwellings he has advanced a stage further, and has become an agriculturist living in villages. From this to the Bronze and early historical periods, there is no great break, and the ruder tribes of barbarians described by Cæsar and Tacitus may well have been the lineal descendants of the Neolithic men whose polished axes and finely-shaped arrow-heads lie scattered over the surface of Europe and are found in innumerable burial-mounds and dolmens.

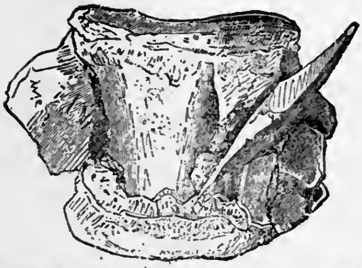
But in Palæolithic times, though we can see constant progress, mankind is still in a state of unmitigated barbarism. Agriculture was clearly unknown, for the hand-mills, pestles, and mortars, which are among the most enduring and abundant relics where grain was used for food, are never met with. Pottery was unknown in all the earlier periods, and it is questionable whether even the rudest forms of baked clay, moulded by hand, are found where there is no intermixture of a subsequent Neolithic habitation. The dog was clearly not a companion of man prior to the era of the Danish kitchen-middens, for the spongy parts of bones which are always gnawed by dogs when dogs are present, are invariably preserved in the *débris* of Palæolithic caves, and the few bones of dogs, wolves, and foxes found with human remains in these caves almost always show that the animals had formed part of the food of the inhabitants.

Other domestic animals were, in all probability, equally unknown, although it has been thought possible that some of the tribes of the reindeer period may have had herds of the half-tame deer, like the modern Laplanders. This conjecture, however, appears to rest solely on the large number of bones and horns found at certain stations, which may have arisen from their having been occupied for a very long period, and as the dog was unknown, it seems probable that no other animals had been domesticated.

As regards clothing, the first certain proofs of its use are afforded by the bone pins and needles, which were evidently employed for fastening the skins of animals together, and the scrapers were probably used for scraping these skins and fashioning the bone implements. It is probable, therefore, that the use of skins as a protection against the cold of the Glacial period, was known at a very early period.

Ornaments, also, are of very early date, as pierced shells, sometimes fossil, and pierced teeth of the bear and other animals are frequently found under circumstances which show that they must have been strung together as necklaces. The skeleton found in a cave at Mentone had a number of perforated shells of Nassa, and a few stag's teeth also perforated, dispersed about the skull, so as to show that they had formed some sort of head ornament. Lumps of red hematite, also, probably used for paint, have been found in some of the caves of the reindeer period

DEVELOPMENT OF THE ARROW.



Flint Arrow in Vertebra of Reindeer.
Palæolithic. La Madeleine.

Palæolithic.
Mammoth Period. Le Moustier.

Palæolithic.
Reindeer Period.
First vestige of barb.

Palæolithic.
Reindeer Period.

Palæolithic.
Reindeer Period.

Neolithic.
Denmark.

Neolithic.
Ireland.

Neolithic.
Denmark.

Recent.
Esquimaux.

(From Lubbock's "Prehistoric Times.")

Captain Cook's description of the savages of Tierra del Fuego would have applied to them, that, "although content to be naked, they were very ambitious to be fine;" and probably like these poor Fuegians, they adorned themselves with streaks of red, black, and white, and wore bracelets and anklets of shell and bone.

If we wish to form some idea of the manners and customs of our Palæolithic ancestors, we must look for them among the existing savage races, whose mode of life, and equipment of tools and weapons, most nearly resemble those of the earliest cave-dwellers. The Australians, the Bushmen of South Africa, the Mincopies of the Andaman Islands, and the Fuegians are probably the lowest specimens of the human race known in modern times; but even these are in some respects further advanced in the arts than the first Palæolithic man. The Bushmen are skilled in the use of the bow, and have discovered the art of poisoning their arrows. The Australians, Mincopies, and Fuegians have canoes, harpoons, and fish-hooks. The latter approach more nearly to the conditions of life of the savages who accumulated the kitchen-middens on the coasts of Denmark at a much later period, and the Bushmen probably represent better those of the cave-men who lived principally on the produce of the chase of large animals, such as the mammoth, rhinoceros, cave bear, horse, and deer. The pigmy Bushman will attack the elephant, the rhinoceros, and even the lion, and often succeed in killing them by pitfalls or poisoned arrows.

The inferences, therefore, to be drawn, alike from the physical development of the individual man, and from the origin and growth of all the faculties which specially distinguish him from the brute creation —language, religion, arts, and science—all point to the conclusion that he is a product of laws of evolution, and not of special or miraculous creation.

Still, admitting this, we must admit on the other hand, that until more of the "missing links" are discovered, and the origin of man is placed on a basis of scientific certainty, there is an opening left for the belief that here, if nowhere else, there was some supernatural interference with the laws of Nature, and that the finger of the clock-maker did here alter the hands of the clock from the position which they would have occupied under the original law of its construction. But if this were so, it must equally in candor be admitted that the miracle did not consist in placing man and woman upon earth, at any recent period, or with faculties in any way developed, but could only have consisted in causing a germ or germs to come into existence, different from any that could have been formed by natural evolution, and containing within them the possibilities of conscious and civilized man, to be developed from the rudest origins by slow and painful progress over countless ages.

Beacon Lights of Science

UTILITARIANISM

By

John Stuart Mill

AUTHOR OF "A SYSTEM OF LOGIC," "PRINCIPLES OF POLITICAL ECONOMY," "ON LIBERTY," ETC., ETC.

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Beacon Lights of Science

UTILITARIANISM

CHAPTER I.

GENERAL REMARKS.

THERE are few circumstances among those which make up the present condition of human knowledge, more unlike what might have been expected, or more significant of the backward state in which speculation on the most important subjects still lingers, than the little progress which has been made in the decision of the controversy respecting the criterion of right and wrong. From the dawn of philosophy, the question concerning the *summum bonum*, or, what is the same thing, concerning the foundation of morality, has been accounted the main problem in speculative thought, has occupied the most gifted intellects, and divided them into sects and schools, carrying on a vigorous warfare against one another. And after more than two thousand years the same discussions continue, philosophers are still ranged under the same contending banners, and neither thinker nor mankind at large seem nearer to being unanimous on the subject, than when the youth Socrates listened to the old Protagoras, and asserted (if Plato's dialogue be grounded on a real conversation) the theory of utilitarianism against the popular morality of the so-called sophist.

It is true that similar confusion and uncertainty, and in some cases similar discordance, exist respecting the first principles of all the sciences, not excepting that which is deemed the most certain of them, mathematics; without much impairing, generally indeed without impairing at all, the trustworthiness of the conclusions of those sciences. An apparent anomaly, the explanation of which is, that the detailed doctrines of a science are not usually deduced from, nor depend for their evidence upon, what are called its first principles. Were it not so, there would be no science more precarious, or whose conclusions were more insufficiently made out, than algebra; which derives none of its certainty from what are commonly taught to learners as its elements, since these, as laid down by some of its most eminent teachers, are as full of fictions as English law, and of mysteries as theology. The truths which are ultimately accepted as the first principles of a science, are really the last results of metaphysical analysis, practised on the elementary notions with which the science is conversant; and their relation to the science is not that of foundations to an edifice, but of roots to a tree, which may perform their office equally well though they be never dug down to and exposed to light. But though in science the particular truths precede the general theory, the contrary might be expected to be the case with a practical art, such as morals or legislation. All action is for the sake of some end, and rules of action, it seems natural to suppose, must take their whole character and color from the end to which they are subservient. When we engage in a pursuit, a clear and precise conception of what we are pursuing would seem to be the first thing we need, instead of the last we are to look forward to. A test of right and wrong must be the means, one would think, of ascertaining what is right or wrong, and not a consequence of having already ascertained it.

The difficulty is not avoided by having recourse to the popular theory of a natural faculty, a sense or instinct, informing us of right and wrong. For—besides that the existence of such a moral instinct is itself one of the matters in dispute—those believers in it who have any pretensions to philosophy, have been obliged to abandon the idea that it discerns what is right or wrong in the particular case in hand, as our other senses discern the sight or sound actually present. Our moral faculty, according to all those of its interpreters who are entitled to the name of thinkers, supplies us only with the general principles of moral judgments; it is a branch of our reason, not of our sensitive faculty; and must be looked to for the abstract doctrines of morality, not for perception of it in the concrete. The intuitive, no less than what may be termed the inductive, school of ethics, insists on the necessity of general laws. They both agree that the morality of an individual action is not a question of direct preception, but of the application of a law to an individual case. They recognize also, to a great extent, the same moral laws; but differ as to their evidence, and the source from which they derive their authority. According to the one opinion, the principles of morals are evident *à priori*, requiring nothing to command assent, except that the meaning of the terms be understood. According to the other doctrine, right and wrong, as well as truth and falsehood, are questions of observation and experience. But both hold equally that morality must be deduced from principles; and the intuitive school affirm as strongly as the inductive, that there is a science of morals. Yet they seldom attempt to make out a list of the *à priori* principles which are to serve as the premises of the science; still more rarely do they make any effort to reduce those various principles to one first principle, or common ground of obligation. They either assume the ordinary precepts of morals as of *à priori* authority, or they lay down as the common groundwork of those maxims, some generality much less obviously authoritative than the maxims themselves, and which has never succeeded in gaining popular acceptance. Yet to support their pretensions there ought either to be some one fundamental principle or law, at the root of all morality, or if there be several, there should be a determinate order of precedence among them; and the one principle, or the rule for deciding between the various principles when they conflict, ought to be self-evident.

To inquire how far the bad effects of this deficiency have been mitigated in practice, or to what extent the moral beliefs of mankind have been vitiated or made uncertain by the absence of any distinct recognition of an ultimate standard, would imply a complete survey and criticism of past and present ethical doctrine. It would, however, be easy to show that whatever steadiness or consistency these moral beliefs have attained, has been mainly due to the tacit influence of a standard not recognized. Although the non-existence of an acknowledged first principle has made ethics not so much a guide as a consecration of men's actual sentiments, still, as men's sentiments, both of favor and of aversion, are greatly influenced by what they suppose to be the effects of things upon their happiness, the principle of utility, or as Bentham latterly called it, the greatest happiness principle, has had a large share in forming the moral doctrines even of those who most scornfully reject its authority. Nor is there any school of thought which refuses to admit that the influence of actions on happiness is a most material and even predominant consideration in many of the details of morals, however unwilling to acknowledge it as the fundamental principle of morality, and the source of moral obligation. I might go much further, and say that to all those *à priori* moralists who deem it necessary to argue at all, utilitarian arguments are indispensable. It is not my present purpose to criticise these thinkers; but I cannot help referring, for illustration, to a systematic treatise by one of the most illustrious of them, the *Metaphysics of Ethics*, by Kant. This remarkable man, whose system of thought will long remain one of the landmarks in the history of philosophical speculation, does, in the treatise in question, lay down an universal first principle as the origin and ground of moral obligation; it is this:—"So act, that the rule on which thou actest would admit of being adopted as a law by all rational beings." But when he begins to deduce from this precept any of the actual duties of morality, he fails, almost grotesquely, to show that there would be any contradiction, any logical (not to say physical) impossibility, in the adoption by all rational beings of the most outrageously immoral rules of conduct. All he shows is that the *consequences* of their universal adoption would be such as no one would choose to incur.

On the present occasion, I shall, without further discussion of the other theories, attempt to contribute something towards the understanding and appreciation of the Utilitarian or Happiness theory, and towards such proof as it is susceptible of. It is evident that this cannot be proof in the ordinary and popular meaning of the term. Questions of ultimate ends are not amenable to direct proof. Whatever can be proved to be good, must be so by being shown to be a means to something admitted to be good without proof. The medical art is proved to be good, by its conducing to health; but how is it possible to prove that health is good? The art of music is good, for the reason, among others, that it produces pleasure; but what proof is it possible to give that pleasure is good? If, then, it is asserted that there is a comprehensive formula, including all things which are in themselves good, and that whatever else is good, is not so as an end, but as a mean, the formula may be accepted or rejected, but is not a subject of what is commonly understood by proof. We are not, however, to infer that its acceptance or rejection must depend on blind impulse, or arbitrary choice. There is a larger meaning of the word proof, in which this question is as amenable to it as any other of the disputed questions of philosophy. The subject is within the cognizance of the rational faculty; and neither does that faculty deal with it solely in the way of intuition. Considerations may be presented capable of determining the intellect either to give or withhold its assent to the doctrine; and this is equivalent to proof.

We shall examine presently of what nature are these considerations; in what manner they apply to the case, and what rational grounds, therefore, can be given for accepting or rejecting the utilitarian formula. But it is a preliminary condition of rational acceptance or rejection, that the formula should be correctly understood. I believe that the very imperfect notion ordinarily formed of its meaning, is the chief obstacle which impedes its reception; and that could it be cleared, even from only the grosser misconceptions, the question would be greatly simplified, and a large proportion of its difficulties removed. Before, therefore, I attempt to enter into the philosophical grounds which can be given for assenting to the utilitarian standard, I shall offer some illustrations of the doctrine itself; with the view of showing more clearly what it is, distinguishing it from what it is not, and disposing of such of the practical objections to it as either originate in, or are closely connected with, mistaken interpretations of its meaning. Having thus prepared the ground, I shall afterwards endeavor to throw such light as I can upon the question, considered as one of philosophical theory.

CHAPTER II.

WHAT UTILITARIANISM IS.

A PASSING remark is all that needs be given to the ignorant blunder of supposing that those who stand up for utility as the test of right and wrong, use the term in that restricted and merely colloquial sense in which utility is opposed to pleasure. An apology is due to the philosophical opponents of utilitarianism, for even the momentary appearance of confounding them with any one capable of so absurd a misconception; which is the more extraordinary, inasmuch as the contrary accusation, of referring everything to pleasure, and that too in its grossest form, is another of the common charges against utilitarianism: and, as has been pointedly remarked by an able writer, the same sort of persons, and often the very same persons, denounce the theory "as impracticably dry when the word utility precedes the word pleasure, and as too practicably voluptuous when the word pleasure precedes the word utility." Those who know anything about the matter are aware that every writer, from Epicurus to Bentham, who maintained the theory of utility, meant by it, not something to be contradistinguished from pleasure, but pleasure itself, together with exemption from pain; and instead of opposing the useful to the agreeable or the ornamental, have always declared that the useful means these, among other things. Yet the common herd, including the herd of writers, not only in newspapers and periodicals, but in books of weight and pretension, are perpetually falling into this shallow mistake. Having caught up the word utilitarian, while knowing nothing whatever about it but its sound, they habitually express by it the rejection, or the neglect, of pleasure in some of its forms; of beauty, of ornament, or of amusement. Nor is the term thus ignorantly misapplied solely in disparagement, but occasionally in compliment; as though it implied superiority to frivolity and the mere pleasures of the moment. And this perverted use is the only one in which the word is popularly known, and the one from which the new generation are acquiring their sole notion of its meaning. Those who introduced the word, but who had for many years discontinued it as a distinctive appellation, may well feel themselves called upon to resume it, if by doing so they can hope to contribute anything towards rescuing it from this utter degradation.*

The creed which accepts as the foundation of morals, Utility, or the Greatest Happiness Principle, holds that actions are right in pro-

*The author of this essay has reason for believing himself to be the first person who brought the word utilitarian into use. He did not invent it, but adopted it from a passing expression in Mr. Galt's *Annals of the Parish*. After using it as a designation for several years, he and others abandoned it from a growing dislike to anything resembling a badge or watchword of sectarian distinction. But as a name for one single opinion, not a set of opinions—to denote the recognition of utility as a standard, not any particular way of applying it—the term supplies a want in the language, and offers, in many cases, a convenient mode of avoiding tiresome circumlocution.

portion as they tend to promote happiness, wrong as they tend to produce the reverse of happiness. By happiness is intended pleasure, and the absence of pain; by unhappiness, pain, and the privation of pleasure. To give a clear view of the moral standard set up by the theory, much more requires to be said; in particular, what things it includes in the ideas of pain and pleasure; and to what extent this is left an open question. But these supplementary explanations do not affect the theory of life on which this theory of morality is grounded—namely, that pleasure, and freedom from pain, are the only things desirable as ends; and that all desirable things (which are as numerous in the utilitarian as in any other scheme) are desirable either for the pleasure inherent in themselves, or as means to the promotion of pleasure and the prevention of pain.

Now, such a theory of life excites in many minds, and among them in some of the most estimable in feeling and purpose, inveterate dislike. To suppose that life has (as they express it) no higher end than pleasure—no better and nobler object of desire and pursuit—they designate as utterly mean and grovelling; as a doctrine worthy only of swine, to whom the followers of Epicurus, were, at a very early period, contemptuously likened; and modern holders of the doctrine are occasionally made the subject of equally polite comparisons by its German, French, and English assailants.

When thus attacked, the Epicureans have always answered, that it is not they, but their accusers, who represent human nature in a degrading light; since the accusation supposes human beings to be capable of no pleasures except those of which swine are capable. If this supposition were true, the charge could not be gainsaid, but would then be no longer an imputation: for if the sources of pleasure were precisely the same to human beings and to swine, the rule of life which is good enough for the one would be good enough for the other. The comparison of the Epicurean life to that of beasts is felt as degrading, precisely because a beast's pleasures do not satisfy a human being's conceptions of happiness. Human beings have faculties more elevated than the animal appetites, and when once made conscious of them, do not regard anything as happiness which does not include their gratification. I do not, indeed, consider the Epicureans to have been by any means faultless in drawing out their scheme of consequences from the utilitarian principle. To do this in any sufficient manner, many Stoic, as well as Christian elements require to be included. But there is no known Epicurean theory of life which does not assign to the pleasures of the intellect, of the feelings and imagination, and of the moral sentiments, a much higher value as pleasures than to those of mere sensation. It must be admitted, however, that utilitarian writers in general have placed the superiority of mental over bodily pleasures chiefly in the greater permanency, safety, uncostliness, &c., of the former—that is, in their circumstantial advantages rather than in their intrinsic nature. And on all these points utilitarians have fully proved their case; but they might have taken the other, and, as it may be called, higher ground, with entire consistency. It is quite compatible with the principle of utility to recognize the fact, that some *kinds* of pleasure are more desirable and more valuable than others. It would be absurd that while, in estimating all other things, quality is considered as well as quantity, the estimation of pleasure should be supposed to depend on quantity alone.

If I am asked, what I mean by difference of quality in pleasures, or what makes one pleasure more valuable than another, merely as a pleasure, except its being greater in amount, there is but one possible answer. Of two pleasures, if there be one to which all or almost all who have experience of both give a decided preference, irrespective of any feeling of moral obligation to prefer it, that is the more desirable pleasure. If one of the two is, by those who are competently acquainted with both, placed so far above the other that they prefer it, even though knowing it to be attended with a greater amount of discontent, and would not resign it for any quantity of the other pleasure which their nature is capable of, we are justified in ascribing to the preferred enjoyment a superiority in quality, so far outweighing quantity as to render it, in comparison, of small account.

Now it is an unquestionable fact that those who are equally acquainted with, and equally capable of appreciating and enjoying, both, do give a most marked preference to the manner of existence which employs their higher faculties. Few human creatures would consent to be changed into any of the lower animals, for a promise of the fullest allowance of a beast's pleasures; no intelligent human being would consent to be a fool, no instructed person would be an ignoramus, no person of feeling and conscience would be selfish and base, even though they should be persuaded that the fool, the dunce, or the rascal is better satisfied with his lot than they are with theirs. They would not resign what they possess more than he, for the most complete satisfaction of all the desires which they have in common with him. If they ever fancy they would, it is only in cases of unhappiness so extreme, that to escape from it they would exchange their lot for almost any other, however undesirable in their own eyes. A being of higher faculties requires more to make him happy, is capable probably of more acute suffering, and is certainly accessible to it at more points, than one of an inferior type; but in spite of these liabilities, he can never really wish to sink into what he feels to be a lower grade of existence. We may give what explanation we please of this unwillingness; we may attribute it to pride, a name which is given indiscriminately to some of the most and to some of the least estimable feelings of which mankind are capable; we may refer it to the love of liberty and personal independence, an appeal to which was with the Stoics one of the most effective means for the inculcation of it; to the love of power, or to the love of excitement, both of which do really enter into and contribute to it: but its most appropriate appellation is a sense of dignity, which all human beings possess in one form or other, and in some, though by no means in exact, proportion to their higher faculties, and which is so essential a part of the happiness of those in whom it is strong, that nothing which conflicts with it could be, otherwise than momentarily, an object of desire to them. Whoever supposes that this preference takes place at a sacrifice of happiness—that the superior being, in anything like equal circumstances, is not happier than the inferior—confounds the two very different ideas, of happiness, and content. It is indisputable that the being whose capacities of enjoyment are low, has the greatest chance of having them fully satisfied; and a highly-endowed being will always feel that any happiness which he can look for, as the world is constituted, is imperfect. But he can learn to bear its imperfections, if they are at all bearable; and they will not make him envy the being who is indeed unconscious of the imperfections, but only because he feels not at all the good which those imperfections qualify. It is better to be a human being dissatisfied that a pig satisfied; better to be Socrates dissatisfied than a fool satisfied. And if the fool, or the pig, is of a different opinion, it is because they only know their own side of the question. The other party to the comparison knows both sides.

It may be objected, that many who are capable of the higher pleasures, occasionally, under the influence of temptation, postpone them to the lower. But this is quite compatible with a full appreciation of the intrinsic superiority of the higher. Men often, from infirmity of character, make their election for the nearer good, though they know it to be the less valuable; and this no less when the choice is between two bodily pleasures, than when it is between bodily and mental. They pursue sensual indulgences to the injury of health, though perfectly aware that health is the greater good. It may be further objected, that many who begin with youthful enthusiasm for everything noble, as they advance in years sink into indolence and selfishness. But I do not believe that those who undergo this very common change, voluntarily choose the lower description of pleasures in preference to the higher. I believe that before they devote themselves exclusively to the one, they have already become incapable of the other. Capacity for the nobler feelings is in most natures a very tender plant, easily killed, not only by hostile influences, but by mere want of sustenance; and in the majority of young persons it speedily dies away if the occupations to which their position in life has devoted them, and the society into which it has thrown them, are not favorable to keeping that higher capacity in exercise. Men lose their high aspirations as they lose their intellectual tastes, because they have not time or opportunity for indulging them; and they addict themselves to inferior pleasures, not because they deliberately prefer them, but because they are either the only ones to which they have access, or the only ones which they are any longer capable of enjoying. It may be questioned whether any one who has remained equally susceptible to both classes of pleasures, ever knowingly and calmly preferred the lower; though many, in all ages, have broken down in an ineffectual attempt to combine both

From this verdict of the only competent judges, I apprehend there can be no appeal. On a question which is the best worth having of two pleasures, or which of two modes of existence is the most grateful to the feelings, apart from its moral attributes and from its consequences, the judgment of those who are qualified by knowledge of both, or, if they differ, that of the majority among them, must be admitted as final. And there needs be the less hesitation to accept this judgment respecting the quality of pleasures, since there is no other tribunal to be referred to even on the question of quantity. What means are there of determining which is the acutest of two pains, or the intensest of two pleasurable sensations, except the general suffrage of those who are familiar with both? Neither pains nor pleasures are homogeneous, and pain is always heterogeneous with pleasure. What is there to decide whether a particular pleasure is worth purchasing at the cost of a particular pain, except the feelings and judgment of the experienced? When, therefore, those feelings and judgment declare the pleasures derived from the higher faculties to be preferable *in kind*, apart from the question of intensity, to those of which the animal nature, disjoined from the higher faculties, is susceptible, they are entitled on this subject to the same regard.

I have dwelt on this point, as being a necessary part of a perfectly just conception of Utility or Happiness, considered as the directive rule of human conduct. But it is by no means an indispensable condition to the acceptance of the utilitarian standard; for that standard is not the agent's own greatest happiness, but the greatest amount of happiness altogether; and if it may possibly be doubted whether a noble character is always the happier for its nobleness, there can be no doubt that it makes other people happier, and that the world in general is immensely a gainer by it. Utilitarianism, therefore, could only attain its end by the general cultivation of nobleness of character, even if each individual were only benefited by the nobleness of others, and his own, so far as happiness is concerned, were a sheer deduction from the benefit. But the bare enunciation of such an absurdity as this last, renders refutation superfluous.

According to the Greatest Happiness Principle, as above explained, the ultimate end, with reference to and for the sake of which all other things are desirable (whether we are considering our own good or that of other people), is an existence exempt as far as possible from pain, and as rich as possible in enjoyments, both in point of quantity and quality; the test of quality, and the rule for measuring it against quantity, being the preference felt by those who, in their opportunities of experience, to which must be added their habits of self-consciousness and self-observation, are best furnished with the means of comparison. This, being, according to the utilitarian opinion, the end of human action, is necessarily also the standard of morality; which may accordingly be defined, the rules and precepts for human conduct, by the observance of which an existence such as has been described might be, to the greatest extent possible, secured to all mankind; and not to them only, but, so far as the nature of things admits, to the whole sentient creation.

Against this doctrine, however, rises another class of objectors, who say that happiness, in any form, cannot be the rational purpose of human life and action; because, in the first place, it is unattainable: and they contemptuously ask, What right hast thou to be happy? a question which Mr. Carlyle clenches by the addition, What right, a short time ago, hadst thou even *to be?* Next, they say, that men can do *without* happiness; that all noble human beings have felt this, and could not have become noble but by learning the lesson of Entsagen, or renunciation; which lesson, thoroughly learnt and submitted to, they affirm to be the beginning and necessary condition of all virtue.

The first of these objections would go to the root of the matter were it well founded; for if no happiness is to be had at all by human beings, the attainment of it cannot be the end of morality, or of any rational conduct. Though, even in that case, something might still be said for the utilitarian theory; since utility includes not solely the pursuit of happiness, but the prevention or mitigation of unhappiness; and if the former aim be chimerical, there will be all the greater scope and more imperative need for the latter, so long at least as mankind think fit to live, and do not take refuge in the simultaneous act of suicide recommended under certain conditions by Novalis. When, however, it is thus positively asserted to be impossible that human life should be happy, the assertion, if not something like a verbal quibble, is at least an exaggeration. If by happiness be meant a continuity of highly pleasurable excitement, it is evident enough that this is impossible. A state of exalted pleasure lasts only moments, or in some cases, and with some intermissions, hours or days, and is the occasional brilliant flash of enjoyment, not its permanent and steady flame. Of this the philosophers who have taught that happiness is the end of life were as fully aware as those who taunt them. The happiness which they meant was not a life of rapture; but moments of such, in an existence made up of few and transitory pains, many and various pleasures, with a decided predominance of the active over the passive, and having as the foundation of the whole, not to expect more from life than it is capable of bestowing. A life thus composed, to those who have been fortunate enough to obtain it, has always appeared worthy of the name of happiness. And such an existence is even now the lot of many, during some considerable portion of their lives. The present wretched education, and wretched social arrangements, are the only real hindrance to its being attainable by almost all.

The objectors perhaps may doubt whether human beings, if taught to consider happiness as the end of life, would be satisfied with such a moderate share of it. But great numbers of mankind have been satisfied with much less. The main constituents of a satisfied life appear to be two, either of which by itself is often found sufficient for the purpose: tranquillity, and excitement. With much tranquillity, many find that they can be content with very little pleasure: with much excitement, many can reconcile themselves to a considerable quantity of pain. There is assuredly no inherent impossibility in enabling even the mass of mankind to unite both; since the two are so far from being incompatible that they are in natural alliance, the prolongation of either being a preparation for, and exciting a wish for, the other. It is only those in whom indolence amounts to a vice, that do not desire excitement after an interval of repose; it is only those in whom the need of excitement is a disease, that feel the tranquillity which follows excitement dull and insipid, instead of pleasurable in direct proportion to the excitement which preceded it. When people who are tolerably fortunate in their outward lot do not find in life sufficient enjoyment to make it valuable to them, the cause generally is, caring for nobody but themselves. To those who have neither public nor private affections, the excitements of life are much curtailed, and in any case dwindle in value as the time approaches when all selfish interests must be terminated by death: while those who leave after them objects of personal affection, and especially those who have also cultivated a fellow-feeling with the collective interests of mankind, retain as lively an interest in life on the eve of death as in the vigor of youth and health. Next to selfishness, the principal cause which makes life unsatisfactory, is want of mental cultivation. A cultivated mind—I do not mean that of a philosopher, but any mind to which the fountains of knowledge have been opened, and which has been taught, in any tolerable degree, to exercise its faculties—finds sources of inexhaustible interest in all that surrounds it; in the objects of nature, the achievements of art, the imaginations of poetry, the incidents of history, the ways of mankind past and present, and their prospects in the future. It is possible, indeed, to become indifferent to all this, and that too without having exhausted a thousandth part of it; but only when one has had from the beginning no moral or human interest in these things, and has sought in them only the gratification of curiosity.

Now there is absolutely no reason in the nature of things why an amount of mental culture sufficient to give an intelligent interest in these objects of contemplation, should not be the inheritance of every one born in a civilized country. As little is there an inherent necessity that any human being should be a selfish egotist, devoid of every feeling or care but those which centre in his own miserable individuality. Something far superior to this is sufficiently common even now, to give ample earnest of what the human species may be made. Genuine private affections, and a sincere interest in the public good, are possible, though in unequal degrees, to every rightly brought up human being. In a world in which there is so much to interest, so much to enjoy, and so much also to correct and improve, every one who has this moderate amount of moral and intellectual requisites is capable of an existence which may be called enviable; and unless such a person, through bad laws, or subjection to the will of others, is denied the liberty to use the sources of happiness within his reach, he will not fail to find this enviable existence, if he escape the positive evils of life, the great sources of physical and mental suffering—such as indigence, disease, and the unkindness, worthlessness, or premature loss of objects of affection. The main stress of the problem lies, therefore, in the contest with these calamities, from which it is a rare good fortune entirely to escape; which, as things now are, cannot be obviated, and often cannot be in any material degree mitigated. Yet no one whose opinion deserves a moment's consideration can doubt that most of the great positive evils of the world are in themselves removable, and will, if human affairs continue to improve, be in the end reduced within narrow limits. Poverty, in any sense implying suffering, may be completely extinguished by the wisdom of society, combined with the good sense and providence of individuals. Even that most intractable of enemies, disease, may be indefinitely reduced in dimensions by good physical and moral education, and proper control of noxious influences; while the progress of science holds out a promise for the future of still more direct conquests over this detestable foe. And every advance in that direction relieves us from some, not only of the chances which cut short our own lives, but, what concerns us still more, which deprive us of those in whom our happiness is wrapt up. As for vicissitudes of fortune, and other disappointments connected with worldly circumstances, these are principally the effect either of gross imprudence, of ill-regulated desires, or of bad or imperfect social institutions. All the grand sources, in short, of human suffering are in a great degree, many of them almost entirely, conquerable by human care and effort; and though their removal is grievously slow—though a long succession of generations will perish in the breach before the conquest is completed, and this world becomes all that, if will and knowledge were not wanting, it might easily be made—yet every mind sufficiently intelligent and generous to bear a part, however small and unconspicuous, in the endeavor, will draw a noble enjoyment from the contest itself, which he would not for any bribe in the form of selfish indulgence consent to be without.

And this leads to the true estimation of what is said by the objectors concerning the possibility, and the obligation, of learning to do without happiness. Unquestionably it is possible to do without happiness; it is done involuntarily by nineteen-twentieths of mankind, even in those parts of our present world which are least deep in barbarism; and it often has to be done voluntarily by the hero or the martyr, for the sake of something which he prizes more than his individual happiness. But this something, what is it, unless the happiness of others, or some of the requisites of happiness? It is noble to be capable of resigning entirely one's own portion of happiness, or chances of it: but, after all, this self-sacrifice must be for some end; it is not its own end; and if we are told that its end is not happiness, but virtue, which is better than happiness, I ask, would the sacrifice be made if the hero or martyr did not believe that it would earn for others immunity from similar sacrifices? Would it be made, if he thought that his renunciation of happiness for himself would produce no fruit for any of his fellow creatures, but to make their lot like his, and place them also in the condition of persons who have renounced happiness? All honor to those who can abnegate for themselves the personal enjoyment of life, when by such renunciation they contribute worthily to increase the amount of happiness in the world; but he who does it, or professes to do it, for any other purpose, is no more deserving of admiration than the ascetic mounted on his pillar. He may be an inspiriting proof of what men *can* do, but assuredly not an example of what they *should*.

Though it is only in a very imperfect state of the world's arrangements that any one can best serve the happiness of others by the absolute sacrifice of his own, yet so long as the world is in that imperfect state, I fully acknowledge that the readiness to make such a sacrifice is the highest virtue which can be found in man. I will add, that in this condition of the world, paradoxical as the assertion may be, the conscious ability to do without happiness gives the best prospect of realizing such happiness as is attainable. For nothing except that consciousness can raise a person above the chances of life, by making him feel that, let fate and fortune do their worst, they have not power to subdue him: which, once felt, frees him from excess of anxiety concerning the evils of life, and enables him, like many a Stoic in the worst times of the Roman Empire, to cultivate in tranquillity the sources of satisfaction accessible to him, without concerning himself about the uncertainty of their duration, any more than about their inevitable end.

Meanwhile, let ultilitarians never cease to claim the morality of self-devotion as a possession which belongs by as good a right to them, as either to the Stoic or to the Transcendentalist. The utilitarian morality does recognize in human beings the power of sacrificing their own greatest good for the good of others. It only refuses to admit that the sacrifice is itself a good. A sacrifice which does not increase, or tend to increase, the sum total of happiness, it considers as wasted. The only self-renunciation which it applauds, is devotion to the happiness, or to some of the means of happiness, of others; either of mankind collectively, or of individuals within the limits imposed by the collective interests of mankind.

I must again repeat, what the assailants of utilitarianism seldom have the justice to acknowledge, that the happiness which forms the utilitarian standard of what is right in conduct, is not the agent's own happiness, but that of all concerned. As between his own happiness and that of others, utilitarianism requires him to be as strictly impartial as a disinterested and benevolent spectator. In the golden rule of Jesus of Nazareth, we read the complete spirit of the ethics of utility. To do as one would be done by, and to love one's neighbor as oneself, constitute the ideal perfection of utilitarian morality. As the means of making the nearest approach to this ideal, utility would enjoin, first, that laws and social arrangements should place the happiness, or (as speaking practically it may be called) the interest, of every individual, as nearly as possible in harmony with the interest of the whole; and secondly, that education and opinion, which have so vast a power over human character, should so use that power as to establish in the mind of every individual an indissoluble association between his own happiness and the good of the whole; especially between his own happiness and the practice of such modes of conduct, negative and positive, as regard for the universal happiness prescribes: so that not only he may be unable to conceive the possibility of happiness to himself, consistently with conduct opposed to the general good, but also that a direct impulse to promote the general good may be in every individual one of the habitual motives of action, and the sentiments connected therewith may fill a large and prominent place in every human being's sentient existence. If the impugners of the utilitarian morality represented it to their own minds in this its true character, I know not what recommendation possessed by any other morality they could possibly affirm to be wanting to it: what more beautiful or more exalted developments of human nature any other ethical system can be supposed to foster, or what springs of action, not accessible to the utilitarian, such systems rely on for giving effect to their mandates.

The objectors to utilitarianism cannot always be charged with representing it in a discreditable light. On the contrary, those among them who entertain anything like a just idea of its disinterested character, sometimes find fault with its standard as being too high for humanity. They say it is exacting too much to require that people shall always act from the inducement of promoting the general interests of society. But this is to mistake the very meaning of a standard of morals, and to confound the rule of action with the motive of it. It is the business of ethics to tell us what are our duties, or by what test we may know them; but no system of ethics requires that the sole motive of all we do shall be a feeling of duty; on the contrary, ninety-nine hundredths of all our actions are done from other motives, and rightly so done, if the rule of duty does not condemn them. It is the more unjust to utilitarianism that this particular misapprehension should be made a ground of objection to it, inasmuch as utilitarian moralists have gone beyond almost all others in affirming that the motive has nothing to do with the morality of the action, though much with the worth of the agent. He who saves a fellow creature from drowning does what is morally right, whether his motive be duty, or the hope of being paid for his trouble: he who betrays the friend that trusts him, is guilty of a crime, even if his object be to serve another friend to whom he is under greater obligations.* But to speak only of actions done from the motive of duty, and in direct obedience to principle: it is a misapprehension of the utilitarian mode of thought, to conceive it as implying that people should fix their minds upon so wide a generality as the world, or society at large. The great majority of good actions are intended, not for the benefit of the world, but for that of individuals, of which the good of the world is made up; and the thoughts of the most virtuous man need not on these occasions travel beyond the particular persons concerned, except so far as is necessary to assure himself that in benefiting them he is not violating the rights—that is, the legitimate and authorized expectations—of any one else. The multiplication of happiness is, according to the

* An opponent, whose intellectual and moral fairness is a pleasure to acknowledge (the Rev. J. Llewelyn Davies), has objected to this passage, saying, "Surely the rightness or wrongness of saving a man from drowning does depend very much upon the motive with which it is done. Suppose that a tyrant, when his enemy jumped into the sea to escape from him, saved him from drowning simply in order that he might inflict upon him more exquisite tortures, would it tend to clearness to speak of that rescue as 'a morally right action?' Or suppose again, according to one of the stock illustrations of ethical inquiries, that a man betrayed a trust received from a friend, because the discharge of it would fatally injure that friend himself or some one belonging to him, would utilitarianism compel one to call the betrayal 'a crime' as much as if it had been done from the meanest motive?"

I submit, that he who saves another from drowning in order to kill him by torture afterwards, does not differ only in motive from him who does the same thing from duty or benevolence; the act itself is different. The rescue of the man is, in the case supposed, only the necessary first step of an act far more atrocious than leaving him to drown would have been. Had Mr. Davies said, "The rightness or wrongness of saving a man from drowning does depend very much"—not upon the motive, but—"upon the *intention*," no utilitarian would have differed from him. Mr. Davies, by an oversight too common not to be quite venial, has in this case confounded the very different ideas of Motive and Intention. There is no point which utilitarian thinkers (and Bentham pre-eminently) have taken more pains to illustrate than this. The morality of the action depends entirely upon the intention—that is, upon what the agent *wills to do*. But the motive, that is, the feeling which makes him will so to do, when it makes no difference in the act, makes none in the morality: though it makes a great difference in our moral estimation of the agent, especially if it indicates a good or a bad habitual *disposition*—a bent of character from which useful, or from which hurtful actions are likely to arise.

utilitarian ethics, the object of virtue: the occasions on which any person (except one in a thousand) has it in his power to do this on an extended scale, in other words, to be a public benefactor, are but exceptional; and on these occasions alone is he called on to consider public utility; in every other case, private utility, the interest or happiness of some few persons, is all he has to attend to. Those alone the influence of whose actions extends to society in general, need concern themselves habitually about so large an object. In the case of abstinences indeed—of things which people forbear to do, from moral considerations, though the consequences in the particular case might be beneficial—it would be unworthy of an intelligent agent not to be consciously aware that the action is of a class which, if practised generally, would be generally injurious, and that this is the ground of the obligation to abstain from it. The amount of regard for the public interest implied in this recognition, is no greater than is demanded by every system of morals; for they all enjoin to abstain from whatever is manifestly pernicious to society.

The same considerations dispose of another reproach against the doctrine of utility, founded on a still grosser misconception of the purpose of a standard of morality, and of the very meaning of the words right and wrong. It is often affirmed that utilitarianism renders men cold and unsympathizing; that it chills their moral feelings towards individuals; that it makes them regard only the dry and hard consideration of the consequences of actions, not taking into their moral estimate the qualities from which those actions emanate. If the assertion means that they do not allow their judgment respecting the rightness or wrongness of an action to be influenced by their opinion of the qualities of the person who does it, this is a complaint not against utilitarianism, but against having any standard of morality at all; for certainly no known ethical standard decides an action to be good or bad because it is done by a good or a bad man, still less because done by an amiable, a brave, or a benevolent man, or the contrary. These considerations are relevant, not to the estimation of actions, but of persons; and there is nothing in the utilitarian theory inconsistent with the fact that there are other things which interest us in persons besides the rightness and wrongness of their actions. The Stoics, indeed, with the paradoxical misuse of language which was part of their system, and by which they strove to raise themselves above all concern about anything but virtue, were fond of saying that he who has that has everything; that he, and only he, is rich, is beautiful, is a king. But no claim of this description is made for the virtuous man by the utilitarian doctrine. Utilitarians are quite aware that there are other desirable possessions and qualities besides virtue, and are perfectly willing to allow to all of them their full worth. They are also aware that a right action does not necessarily indicate a virtuous character, and that actions which are blameable often proceed from qualities entitled to praise. When this is apparent in any particular case, it modifies their estimation, not certainly of the act, but of the agent. I grant that they are, notwithstanding, of opinion, that in the long run the best proof of a good character is good actions; and resolutely refuse to consider any mental disposition as good, of which the predominant tendency is to produce bad conduct. This makes them unpopular with many people; but it is an unpopularity which they must share with every one who regards the distinction between right and wrong in a serious light; and the reproach is not one which a conscientious utilitarian need be anxious to repel.

If no more be meant by the objection than that many utilitarians look on the morality of actions, as measured by the utilitarian standard, with too exclusive a regard, and do not lay sufficient stress upon the other beauties of character which go towards making a human being loveable or admirable, this may be admitted. Utilitarians who have cultivated their moral feelings, but not their sympathies nor their artistic perceptions, do fall into this mistake; and so do all other moralists under the same conditions. What can be said in excuse for other moralists is equally available for them, namely, that if there is to be any error, it is better that it should be on that side. As a matter of fact, we may affirm that among utilitarians as among adherents of other systems there is every imaginable degree of rigidity and of laxity in the application of their standard: some are even puritanically rigorous, while others are as indulgent as can possibly be desired by sinner or by sentimentalist. But on the whole, a doctrine which brings prominently forward the interest that mankind have in the repression and prevention of conduct which violates the moral law is likely to be inferior to no other in turning the sanctions of opinion against such violations. It is true, the question, What does violate the moral law? is one on which those who recognize different standards of morality are likely now and then to differ. But difference of opinion on moral questions was not first introduced into the world by utilitarianism, while that doctrine does supply, if not always an easy, at all events a tangible and intelligible mode of deciding such differences.

It may not be superfluous to notice a few more of the common misapprehensions of utilitarian ethics, even those which are so obvious and gross that it might appear impossible for any person of candor and intelligence to fall into them: since persons, even of considerable mental endowments, often give themselves so little trouble to understand the bearings of any opinion against which they entertain a prejudice and men are in general so little conscious of this voluntary ignorance as a defect, that the vulgarest misunderstandings of ethical doctrines are continually met with in the deliberate writings of persons of the greatest pretensions both to high principle and to philosophy. We not uncommonly hear the doctrine of utility inveighed against as a *godless* doctrine. If it be necessary to say anything at all against so mere an assumption, we may say that the question depends upon what idea we have formed of the moral character of the Deity. If it be a true belief that God desires, above all things, the happiness of his creatures, and that this was his purpose in their creation, utility is not only not a godless doctrine, but more profoundly religious than any other. If it be meant that utilitarianism does not recognize the revealed will of God as the supreme law of morals, I answer, that an utilitarian who believes in the perfect goodness and wisdom of God, necessarily believes that whatever God has thought fit to reveal on the subject of morals, must fulfil the requirements of utility in a supreme degree. But others besides utilitarians have been of opinion that the Christian revelation was intended, and is fitted, to inform the hearts and minds of mankind with a spirit which should enable them to find for themselves what is right, and incline them to do it when found, rather than to tell them, except in a very general way, what it is: and that we need a doctrine of ethics, carefully followed out, to *interpret* to us the will of God. Whether this opinion is correct or not, it is superfluous here to discuss; since whatever aid religion, either natural or revealed, can afford to ethical investigation, is as open to the utilitarian moralist as to any other. He can use it as the testimony of God to the usefulness or hurtfulness of any given course of action, by as good a right as others can use it for the indication of a transcendental law, having no connection with usefulness or with happiness.

Again, Utility is often summarily stigmatized as an immoral doctrine by giving it the name of Expediency, and taking advantage of the popular use of that term to contrast it with Principle. But the Expedient, in the sense in which it is opposed to the Right, generally means that which is expedient for the particular interest of the agent himself; as when a minister sacrifices the interest of his country to keep himself in place. When it means anything better than this, it means that which is expedient for some immediate object, some temporary purpose, but which violates a rule whose observance is expedient in a much higher degree. The Expedient, in this sense, instead of being the same thing with the useful, is a branch of the hurtful. Thus, it would often be expedient, for the purpose of getting over some momentary embarrassment, or attaining some object immediately useful to ourselves or others, to tell a lie. But inasmuch as the cultivation in ourselves of a sensitive feeling on the subject of veracity, is one of the most useful, and the enfeeblement of that feeling one of the most hurtful, things to which our conduct can be instrumental; and inasmuch as any, even unintentional, deviation from truth, does that much towards weakening the trustworthiness of human assertion, which is not only the principal support of all present social well-being, but the insufficiency of which does more than any one thing that can be named to keep back civilization, virtue, everything on which human happiness on the largest scale depends; we feel that the violation, for a present advantage, of a rule of such transcendent expediency, is not expedient, and that he who, for the sake of a convenience to himself or to some other individual, does what depends on him to deprive mankind of the good, and inflict upon them the evil, involved in the greater or less reliance which they can place in each other's word, acts the part of one of their worst enemies. Yet that even this rule, sacred as it is, admits of possible exceptions, is acknowledged by all moralists; the chief of which is when the withholding of some fact (as of information from a malefactor, or of bad news from a person dangerously ill) would preserve some one (especially a person other than oneself) from great and unmerited evil, and when the withholding can only be effected by denial. But in order that the exception may not extend itself beyond the need, and may have the least possible effect in weakening reliance on veracity, it ought to be recognized, and, if possible, its limits defined; and if the principle of utility is good for anything, it must be good for weighing these conflicting utilities against one another, and marking out the region within which one or the other preponderates.

Again, defenders of utility often find themselves called upon to reply to such objections as this — that there is not time, previous to action, for calculating and weighing the effects of any line of conduct on the general happiness. This is exactly as if any one were to say that it is impossible to guide our conduct by Christianity, because there is not time, on every occasion on which anything has to be done, to read through the Old and New Testaments. The answer to the objection is, that there has been ample time, namely, the whole past duration of the human species. During all that time mankind have been learning by experience the tendencies of actions; on which experience all the prudence, as well as all the morality of life, is dependent. People talk as if the commencement of this course of experience had hitherto been put off, and as if, at the moment when some man feels tempted to meddle with the property or life of another, he had to begin considering for the first time whether murder and theft are injurious to human happiness. Even then I do not think that he would find the question very puzzling; but, at all events, the matter is now done to his hand. It is truly a whimsical supposition, that if mankind were agreed in considering utility to be the test of morality, they would remain without any agreement as to what *is* useful, and would take no measures for having their notions on the subject taught to the young, and enforced by law and opinion. There is no difficulty in proving any ethical standard whatever to work ill, if we suppose universal idiocy to be conjoined with it, but on any hypothesis short of that, mankind must by this time have acquired positive beliefs as to the effects of some actions on their happiness: and the beliefs which have thus come down are the rules of morality for the multitude, and for the philosopher until he has succeeded in finding better. That philosophers might easily do this, even now, on many subjects; that the received code of ethics is by no means of divine right; and that mankind have still much to learn as to the effects of actions on the general happiness, I admit, or rather, earnestly maintain. The corollaries from the principle of utility, like the precepts of every practical art, admit of indefinite improvement, and, in a progressive state of the human mind, their improvement is perpetually going on. But to consider the rules of morality as improvable, is one thing; to pass over the intermediate generalizations entirely, and endeavor to test each individual action directly by the first principle, is another. It is a strange notion that the acknowledgment of a first principle is inconsistent with the admission of secondary ones. To inform a traveller respecting the place of his ultimate destination, is not to forbid the use of land-marks and direction-posts on the way. The proposition that happiness is the end and aim of morality, does not mean that no road ought to be laid down to that goal, or that persons going thither should not be advised to take one direction rather than another. Men really ought to leave off talking a kind of nonsense on this subject, which they would neither talk nor listen to on other matters of practical concernment. Nobody argues that the art of navigation is not founded on astronomy, because sailors cannot wait to calculate the Nautical Almanac. Being rational creatures, they go to sea with it ready calculated; and all rational creatures go out upon the sea of life with their minds made up on the common questions of right and wrong, as well as on many of the far more difficulty question of wise and foolish. And this, as long as foresight is a human quality, it is to be presumed they will continue to do. Whatever we adopt as the fundamental principle of morality, we require subordinate principles to apply it by: the impossibility of doing without them, being common to all systems, can afford no argument against any one in particular; but gravely to argue as if no such secondary principles could be had, and as if mankind had remained till now, and always must remain, without drawing any general conclusions from the experience of human life, is as high a pitch, I think, as absurdity has ever reached in philosophical controversy.

The remainder of the stock arguments against utilitarianism mostly consist in laying to its charge the common infirmities of human nature, and the general difficulties which embarrass conscientious persons in shaping their course through life. We are told that an utilitarian will be apt to make his own particular case an exception to moral rules, and, when under temptation, will see an utility in the breach of a rule, greater than he will see in its observance. But is utility the only creed which is able to furnish us with excuses for evil doing, and means of cheating our own conscience? They are afforded in abundance by all doctrines which recognize as a fact in morals the existence of conflicting considerations; which all doctrines do, that have been believed by sane persons. It is not the fault of any creed, but of the complicated nature of human affairs, that rules of conduct cannot be so framed as to require no exceptions, and that hardly any kind of action can safely be laid down as either always obligatory or always condemnable. There is no ethical creed which does not temper the rigidity of its laws, by giving a certain latitude, under the moral responsibility of the agent, for accommodation to peculiarities of circumstances; and under every creed, at the opening thus made, self-deception and dishonest casuistry get in. There exists no moral system under which there do not arise unequivocal cases of conflicting obligation. These are the real difficulties, the knotty points both in the theory of ethics, and in the conscientious guidance of personal conduct. They are overcome practically with greater or with less success according to the intellect and virtue of the individual; but it can hardly be pretended that any one will be the less qualified for dealing with them, from possessing an ultimate standard to which conflicting rights and duties can be referred. If utility is the ultimate source of moral obligations, utility may be invoked to decide between them when their demands are incompatible. Though the application of the standard may be difficult, it is better than none at all: while in other systems, the moral laws all claiming independent authority, there is no common umpire entitled to interfere between them; their claims to precedence one over another rest on little better than sophistry, and unless determined, as they generally are, by the unacknowledged influence of considerations of utility, afford a free scope for the action of personal desires and partialities. We must remember that only in these cases of conflict between secondary principles is it requisite that first principles should be appealed to. There is no case of moral obligation in which some secondary principle is not involved; and if only one, there can seldom be any real doubt which one it is, in the mind of any person by whom the principle itself is recognized.

CHAPTER III.

OF THE ULTIMATE SANCTION OF THE PRINCIPLE OF UTILITY.

THE question is often asked, and properly so, in regard to any supposed moral standard—What is its sanction? what are the motives to obey it? or more specifically, what is the source of its obligation? whence does it derive its binding force? It is a necessary part of moral philosophy to provide the answer to this question; which, though frequently assuming the shape of an objection to the utilitarian morality, as if it had some special applicability to that above others, really arises in regard to all standards. It arises, in fact, whenever a person is called on to *adopt* a standard or refer morality to any basis on which he has not been accustomed to rest it. For the customary morality, that which education and opinion have consecrated, is the only one which presents itself to the mind with the feeling of being *in itself* obligatory: and when a person is asked to believe that this morality *derives* its obligation from some general principle round which custom has not thrown the same halo, the assertion is to him a paradox; the supposed corollaries seem to have a more binding force than the original theorem; the superstructure seems to stand better without, than with, what is represented as its foundation. He says to himself, I feel that I am bound not to rob or murder, betray or deceive; but why am I bound to promote the general happiness? If my own happiness lies in something else, why may I not give that the preference?

If the view adopted by the utilitarian philosophy of the nature of the moral sense be correct, this difficulty will always present itself, until the influences which form moral character have taken the same hold of the principle which they have taken of some of the consequences—until, by the improvement of education, the feeling of unity with our fellow creatures shall be (what it cannot be doubted that Christ intended it to be) as deeply rooted in our character, and to our own consciousness as completely a part of our nature, as the horror of crime is in an ordinarily well-brought-up young person. In the meantime, however, the difficulty has no peculiar application to the doctrine of utility, but is inherent in every attempt to analyze morality and reduce it to principles; which, unless the principle is already in men's minds invested with as much sacredness as any of its applications, always seems to divest them of a part of their sanctity.

The principle of utility either has, or there is no reason why it might not have, all the sanctions which belong to any other system of morals. Those sanctions are either external or internal. Of the external sanctions it is not necessary to speak at any length. They are, the hope of favor and the fear of displeasure from our fellow creatures or from the Ruler of the Universe, along with whatever we may have of sympathy or affection for them or of love and awe of Him, inclining us to do His will independently of selfish consequences. There is evidently no reason why all these motives for observance should not attach themselves to the utilitarian morality, as completely and as powerfully as to any other. Indeed, those of them which refer to our fellow creatures are sure to do so, in proportion to the amount of general intelligence; for whether there be any other ground of moral obligation than the general happiness or not, men do desire happiness; and however imperfect may be their own practice, they desire and commend all conduct in others towards themselves, by which they think their happiness is promoted. With regard to the religious motive, if men believe, as most profess to do, in the goodness of God, those who think that conduciveness to the general happiness is the essence, or even only the criterion, of good, must necessarily believe that it is also that which God approves. The whole force therefore of external reward and punishment, whether physical or moral, and whether proceeding from God or from our fellow men, together with all that the capacities of human nature admit, of disinterested devotion to either, become available to enforce the ultilitarian morality, in proportion as that morality is recognized; and the more powerfully, the more the appliances of education and general cultivation are bent to the purpose.

So far as to external sanctions. The internal sanction of duty, whatever our standard of duty may be, is one and the same—a feeling in our own mind; a pain, more or less intense, attendant on violation of duty, which in properly-cultivated moral natures rises, in the more serious cases, into shrinking from it as an impossibility. This feeling, when disinterested, and connecting itself with the pure idea of duty, and not with some particular form of it, or with any of the merely accessory circumstances, is the essence of Conscience; though in that complex phenomenon as it actually exists, the simple fact is in general all encrusted over with collateral associations, derived from sympathy, from love, and still more from fear; from all the forms of religious feeling; from the recollections of childhood and of all our past life; from self-esteem, desire of the esteem of others, and occasionally even self-abasement. This extreme complication is, I apprehend, the origin of the sort of mystical character which, by a tendency of the human mind of which there are many other examples, is apt to be attributed to the idea of moral obligation, and which leads people to believe that the idea cannot possible attach itself to any other objects than those which, by a supposed mysterious law, are found in our present experience to excite it. Its binding force, however, consists in the existence of a mass of feeling which must be broken through in order to do what violates our standard of right, and which, if we do nevertheless violate that standard, will probably have to be encountered afterwards in the form of remorse. Whatever theory we have of the nature or origin of conscience, this is what essentially constitutes it.

The ultimate sanction, therefore, of all morality (external motives apart) being a subjective feeling in our own minds, I see nothing embarrassing to those whose standard is utility, in the question, what is the sanction of that particular standard? We may answer, the same as of all other moral standards—the conscientious feelings of mankind. Undoubtedly this sanction has no binding efficacy on those who do not possess the feelings it appeals to; but neither will these persons be more obedient to any other moral principle than to the utilitarian one. On them morality of any kind has no hold but through the external sanctions. Meanwhile the feelings exist, a fact in human nature, the reality of which, and the great power with which they are capable of acting on those in whom they have been duly cultivated, are proved by experience. No reason has ever been shown why they may not be cultivated to as great intensity in connection with the utilitarian, as with any other rule of morals.

There is, I am aware, a disposition to believe that a person who sees in moral obligation a transcendental fact, an objective reality belonging to the province of "Things in themselves," is likely to be more obedient to it than one who believes it to be entirely subjective, having its seat in human consciousness only. But whatever a person's opinion may be on this point of Ontology, the force he is really urged by is his own subjective feeling, and is exactly measured by its strength. No one's belief that Duty is an objective reality is stronger than the belief that God is so; yet the belief in God, apart from the expectation of actual reward and punishment, only operates on conduct through, and in proportion to, the subjective religious feeling. The sanction, so far as it is disinterested, is always in the mind itself; and the notion, therefore, of the transcendental moralists must be, that this sanction will not exist *in* the mind unless it is believed to have its root out of the mind; and that if a person is able to say to himself, That which is restraining me, and which is called my conscience, is only a feeling in my own mind, he may possibly draw the conclusion that when the feeling ceases the obligation ceases, and that if he find the feeling inconvenient, he may disregard it, and endeavor to get rid of it. But is this danger confined to the utilitarian morality? Does the belief that moral obligation has its seat outside the mind make the feeling of it too strong to be got rid of? The fact is so far otherwise, that all moralists admit and lament the ease with which, in the generality of minds, conscience can be silenced or stifled. The question, Need I obey my conscience? is quite as often put to themselves by persons who never heard of the principle of utility, as by its adherents. Those whose conscientious feelings are so weak as to allow of their asking this question, if they answer it affirmatively, will not do so because they believe in the transcendental theory, but because of the external sanctions.

It is not necessary, for the present purpose, to decide whether the feeling of duty is innate or implanted. Assuming it to be innate, it is an open question to what objects it naturally attaches itself; for the philosophic supporters of that theory are now agreed that the intuitive perception is of principles of morality, and not of the details. If there be anything innate in the matter, I see no reason why the feeling which is innate should not be that of regard to the pleasures and pains of others. If there is any principle of morals which is intuitively obligatory, I should say it must be that. If so, the intuitive ethics would coincide with the utilitarian, and there would be no further quarrel between them. Even as it is, the intuitive moralists, though they believe that there are other intuitive moral obligations, do already believe this to be one; for they unanimonsly hold that a large *portion* of morality turns upon the consideration due to the interests of our fellow creatures. Therefore, if the belief in the transcendental origin of moral obligation gives any additional efficacy to the internal sanction it appears to me that the utilitarian principle has already the benefit of it.

On the other hand, if, as is my own belief, the moral feelings are not innate, but acquired, they are not for that reason the less natural. It is natural to man to speak, to reason, to build cities, to cultivate the ground, though these are acquired faculties. The moral feelings are not indeed a part of our nature, in the sense of being in any perceptible degree present in all of us; but this, unhappily, is a fact admitted by those who believe the most strenuously in their transcendental origin. Like the other acquired capacities above referred to, the moral faculty, if not a part of our nature, is a natural outgrowth from it; capable, like them, in a certain small degree, of springing up spontaneously; and susceptible of being brought by cultivation to a high degree of development. Unhappily it is also susceptible, by a sufficient use of the external sanctions and of the force of early impressions, of being cultivated in almost any direction: so that there is hardly anything so absurd or so mischievous that it may not, by means of these influences, be made to act on the human mind with all the authority of conscience. To doubt that the same potency might be given by the same means to the principle of utility, even if it had no foundation in human nature, would be flying in the face of all experience.

But moral associations which are wholly of artificial creation, when intellectual culture goes on, yield by degrees to the dissolving force of analysis: and if the feeling of duty, when associated with utility, would appear equally arbitrary; if there were no leading department of our nature, no powerful class of sentiments, with which that association would harmonize, which would make us feel it congenial, and incline us not only to foster it in others (for which we have abundant interested motives), but also to cherish it in ourselves; if there were not, in short, a natural basis of sentiment for utilitarian morality, it might well happen that this association also, even after it had been implanted by education, might be analyzed away.

But there *is* this basis of powerful natural sentiment; and this it is which, when once the general happiness is recognized as the ethical standard, will constitute the strength of the utilitarian morality. This firm foundation is that of the social feelings of mankind; the desire to be in unity with our fellow creatures, which is already a powerful principle in human nature, and happily one of those which tend to become stronger, even without express inculcation, from the influences of advancing civilization. The social state is at once so natural, so necessary, and so habitual to man, that, except in some unusual circumstances or by an effort of voluntary abstraction, he never conceives himself otherwise than as a member of a body; and this association is riveted more and more, as mankind are further removed from the state of savage independence. Any condition, therefore, which is essential to a state of society, becomes more and more an inseparable part of every person's conception of the state of things which he is born into, and which is the destiny of a human being. Now, society between human beings, except in the relation of master and slave, is manifestly impossible on any other footing than that the interests of all are to be consulted. Society between equals can only exist on the understanding that the interests of all are to be regarded equally. And since in all states of civilization, every person, except an absolute monarch, has equals, every one is obliged to live on these terms with somebody; and in every age some advance is made towards a state in which it will be impossible to live permanently on other terms with anybody. In this way people grow up unable to conceive as possible to them a state of total disregard of other people's interests. They are under a necessity of conceiving themselves as at least abstaining from all the grosser injuries, and (if only for their own protection) living in a state of constant protest against them. They are also familiar with the fact of co-operating with others, and proposing to themselves a collective, not an individual interest, as the aim (at least for the time being) of their actions. So long as they are co-operating, their ends are identified with those of others; there is at least a temporary feeling that the interests of others are their own interests. Not only does all strengthening of social ties, and all healthy growth of society, give to each individual a stronger personal interest in practically consulting the welfare of others; it also leads him to identify his *feelings* more and more with their good, or at least with an ever greater degree of practical consideration for it. He comes, as though instinctively, to be conscious of himself as a being who *of course* pays regard to others. The good of others becomes to him a thing naturally and necessarily to be attended to, like any of the physical conditions of our existence. Now, whatever amount of this feeling a person has, he is urged by the strongest motives both of interest and of sympathy to demonstrate it, and to the utmost of his power encourage it in others; and even if he has none of it himself, he is as greatly interested as any one else that others should have it. Consequently, the smallest germs of the feeling are laid hold of and nourished by the contagion of sympathy and the influences of education; and a complete web of corroborative association is woven round it, by the powerful agency of the external sanctions. This mode of conceiving ourselves and human life, as civilization goes on, is felt to be more and more natural. Every step in political improvement renders it more so, by removing the sources of opposition of interest, and leveling those inequalities of legal privilege between individuals or classes, owing to which there are large portions of mankind whose happiness it is still practicable to disregard. In an improving state of the human mind, the influences are constantly on the increase, which tend to generate in each individual a feeling of unity with all the rest; which feeling, if perfect, would make him never think of, or desire, any beneficial condition for himself, in the benefits of which they are not included. If we now suppose this feeling of unity to be taught as a religion, and the whole force of education, of institutions, and of opinion, directed, as it once was in the case of religion, to make every person grow up from infancy surrounded on all sides both by the profession and by the practice of it, I think that no one, who can realize this conception, will feel any misgiving about the sufficiency of the ultimate sanction for the Happiness morality. To any ethical student who finds the realization difficult, I recommend, as a means of facilitating it, the second of M. Comte's two principal works, the *Système de Politique Positive.* I entertain the strongest objections to the system of politics and morals set forth in that treatise; but I think it has superabundantly shown the possibility of giving to the service of humanity, even without the aid of belief in a Providence, both the physical power and the social efficacy of a religion; making it take hold of human life, and color all thought, feeling, and action, in a manner of which the greatest ascendency ever exercised by any religion may be but a type and foretaste; and of which the danger is, not that it should be insufficient, but that it should be so excessive as to interfere unduly with human freedom and individuality.

Neither is it necessary to the feeling which constitutes the binding force of the utilitarian morality on those who recognize it, to wait for those social influences which would make its obligation felt by mankind at large. In the comparatively early state of human advancement in which we now live, a person cannot indeed feel that entireness of sympathy with all others, which would make any real discordance in the general direction of their conduct in life impossible; but already a person in whom the social feeling is at all developed, cannot bring himself to think of the rest of his fellow creatures as struggling rivals with him for the means of happiness, whom he must desire to see defeated in their object in order that he may succeed in his. The deeply-rooted conception which every individual even now has of himself as a social being, tends to make him feel it one of his natural wants that there should be harmony between his feelings and aims and those of his fellow creatures. If differences of opinion and of mental culture make it impossible for him to share many of their actual feelings—perhaps make him denounce and defy those feelings—he still needs to be conscious that his real aim and theirs do not conflict; that he is not opposing himself to what they really wish for, namely, their own good, but is, on the contrary, promoting it. This feeling in most individuals is much inferior in strength to their selfish feelings, and is often wanting altogether. But to those who have it, it possesses all the characters of a natural feeling. It does not present itself to their minds as a superstition of education, or a law despotically imposed by the power of society, but as an attribute which it would not be well for them to be without. This conviction is the ultimate sanction of the greatest-happiness morality. This it is which makes any mind, of well-developed feelings, work with, and not against, the outward motives to care for others, afforded by what I have called the external sanctions; and when those sanctions are wanting, or act in an opposite direction, constitutes in itself a powerful internal binding force, in proportion to the sensitiveness and thoughtfulness of the character; since few but those whose mind is a moral blank, could bear to lay out their course of life on the plan of paying no regard to others except so far as their own private interest compels.

CHAPTER IV.

OF WHAT SORT OF PROOF THE PRINCIPLE OF UTILITY IS SUSCEPTIBLE.

IT has already been remarked, that questions of ultimate ends do not admit of proof, in the ordinary acceptation of the term. To be incapable of proof by reasoning is common to all first principles; to the first premises of our knowledge, as well as to those of our conduct. But the former, being matters of fact, may be the subject of a direct appeal to the faculties which judge of fact—namely, our senses, and our internal consciousness. Can an appeal be made to the same faculties on questions of practical ends? Or by what other faculty is cognizance taken of them?

Questions about ends are, in other words, questions what things are desirable. The utilitarian doctrine is, that happiness is desirable, and the only thing desirable, as an end; all other things being only desirable as means to that end. What ought to be required of this doctrine—what conditions is it requisite that the doctrine should fulfil—to make good its claim to be believed?

The only proof capable of being given that an object is visible, is that people actually see it. The only proof that a sound is audible, is that people hear it: and so of the other sources of our experience. In like manner, I apprehend, the sole evidence it is possible to produce that anything is desirable, is that people do actually desire it. If the end which the utilitarian doctrine proposes to itself were not, in theory and in practice, acknowledged to be an end, nothing could ever convince any person that it was so. No reason can be given why the general happiness is desirable, except that each person, so far as he believes it to be attainable, desires his own happiness. This, however, being a fact, we have not only all the proof which the case admits of, but all which it is possible to require, that happiness is a good: that each person's happiness is a good to that person, and the general happiness, therefore, a good to the aggregate of all persons. Happiness has made out its title as *one* of the ends of conduct, and consequently one of the criteria of morality.

But it has not, by this alone, proved itself to be the sole criterion. To do that, it would seem, by the same rule, necessary to show, not only that people desire happiness, but that they never desire anything else. Now it is palpable that they do desire things which, in common language, are decidedly distinguished from happiness. They desire, for example, virtue, and the absence of vice, no less really than pleasure and the absence of pain. The desire of virtue is not as universal, but it is as authentic a fact, as the desire of happiness. And hence the opponents of the utilitarian standard deem that they have a right to infer that there are other ends of human action besides happiness, and that happiness is not the standard of approbation and disapprobation.

But does the utilitarian doctrine deny that people desire virtue, or maintain that virtue is not a thing to be desired? The very reverse. It maintains not only that virtue is to be desired, but that it is to be desired disinterestedly, for itself. Whatever may be the opinion of utilitarian moralists as to the original conditions by which virtue is made virtue; however they may believe (as they do) that actions and dispositions are only virtuous because they promote another end than virtue; yet this being granted, and it having been decided, from considerations of this description, which *is* virtuous, they not only place virtue at the very head of the things which are good as means to the ultimate end, but they also recognize as a psychological fact the possibility of its being, to the individual, a good in itself, without looking to any end beyond it; and hold, that the mind is not in a right state, not in a state conformable to Utility, not in the state most conducive to the general happiness, unless it does love virtue in this manner—as a thing desirable in itself, even although, in the individual instance, it should not produce those other desirable consequences which it tends to produce, and on account of which it is held to be virtue. This opinion is not, in the smallest degree, a departure from the Happiness principle. The ingredients of happiness are very various, and each of them is desirable in itself, and not merely when considered as swelling an aggregate. The principle of utility does not mean that any given pleasure, as music, for instance, or any given exemption from pain, as for example, health, are to be looked upon as means to a collective something termed happiness, and to be desired on that account. They are desired and desirable in and for themselves; besides being means, they are a part of the end. Virtue, according to the utilitarian doctrine, is not naturally and originally part of the end, but it is capable of becoming so; and in those who love it disinterestedly it has become so, and is desired and cherished, not as a means to happiness, but as a part of their happiness.

To illustrate this further, we may remember that virtue is not the only thing, originally a means, and which if it were not a means to anything else, would be and remain indifferent, but which by association with what it is a means to, comes to be desired for itself, and that too with the utmost intensity. What, for example, shall we say of the love of money? There is nothing originally more desirable about money than about any heap of glittering pebbles. Its worth is solely that of the things which it will buy; the desires for other things than itself, which it is a means of gratifying. Yet the love of money is not only one of the strongest moving forces of human life, but money is, in many cases, desired in and for itself; the desire to possess it is often stronger than the desire to use it, and goes on increasing when all the desires which point to ends beyond it, to be compassed by it, are falling off. It may then be said truly, that money is desired not for the sake of an end, but as part of the end. From being a means to happiness, it has come to be itself a principle ingredient of the individual's conception of happiness. The same may be said of the majority of the great objects of human life—power, for example, or fame; except that to each of these there is a certain amount of immediate pleasure annexed, which has at least the semblance of being naturally inherent in them; a thing which cannot be said of money. Still, however, the strongest natural attraction, both of power and of fame, is the immense aid they give to the attainment of our other wishes; and it is the strong association thus generated between them and all our objects of desire, which gives to the direct desire of them the intensity it often assumes, so as in some characters to surpass in strength all other desires. In these cases the means have become a part of the end, and a more important part of it than any of the things which they are means to. What was once desired as an instrument for the attainment of happiness, has come to be desired for its own sake. In being desired for its own sake it is, however, desired as *part* of happiness. The person is made, or thinks he would be made, happy by its mere possession; and is made unhappy by failure to obtain it. The desire of it is not a different thing from the desire of happiness, any more than the love of music, or the desire of health. They are included in happiness. They are some of the elements of which the desire of happiness is made up. Happiness is not an abstract idea, but a concrete whole; and these are some of its parts. And the utilitarian standard sanctions and approves their being so. Life would be a poor thing, very ill provided with sources of happiness, if there were not this provision of nature, by which things originally indifferent, but conducive to, or otherwise associated with, the satisfaction of our primitive desires, become in themselves sources of pleasure more valuable than the primitive pleasures, both in permanency, in the space of human existence that they are capable of covering, and even in intensity.

Virtue, according to the utilitarian conception, is a good of this description. There was no original desire of it, or motive to it, save its conduciveness to pleasure, and especially to protection from pain. But through the association thus formed, it may be felt a good in itself, and desired as such with as great intensity as any other good; and with this difference between it and the love of money, of power, or of fame, that all of these may, and often do, render the individual noxious to the other members of the society to which he belongs, whereas there is nothing which makes him so much a blessing to them as the cultivation of the disinterested love of virtue. And consequently, the utilitarian standard, while it tolerates and approves those other acquired desires, up to the point beyond which they would be more injurious to the general happiness than promotive of it, enjoins and requires the cultivation of the love of virtue up to the greatest strength possible, as being above all things important to the general happiness.

It results from the preceding considerations, that there is in reality nothing desired except happiness. Whatever is desired otherwise than as a means to some end beyond itself, and ultimately to happiness, is desired as itself a part of happiness, and is not desired for itself until it has become so. Those who desire virtue for its own sake, desire it either because the consciousness of it is a pleasure, or because the consciousness of being without it is a pain, or for both reasons united; as in truth the pleasure and pain seldom exist separately, but almost always together, the same person feeling pleasure in the degree of virtue attained, and pain in not having attained more. If one of these gave him no pleasure, and the other no pain, he would not love or desire virtue, or would desire it only for the other benefits which it might produce to himself or to persons whom he cared for.

We have now, then, an answer to the question, of what sort of proof the principle of utility is susceptible. If the opinion which I have now stated is psychologically true—if human nature is so constituted as to desire nothing which is not either a part of happiness or a means of happiness, we can have no other proof, and we require no other, that these are the only things desirable. If so, happiness is the sole end of human action, and the promotion of it the test by which to judge of all human conduct; from whence it necessarily follows that it must be the criterion of morality, since a part is included in the whole.

And now to decide whether this is really so; whether mankind do desire nothing for itself but that which is a pleasure to them, or of which the absence is a pain; we have evidently arrived at a question of fact and experience, dependent, like all similar questions, upon evidence. It can only be determined by practised self-consciousness and self-observation, assisted by observation of others. I believe that these sources of evidence, impartially consulted, will declare that desiring a thing and finding it pleasant, aversion to it and thinking of it as painful, are phenomena entirely inseparable, or rather two parts of the same phenomenon; in strictness of language, two different modes of naming the same psychological fact: that to think of an object as desirable (unless for the sake of its consequences), and to think of it as pleasant, are one and the same thing; and that to desire anything, except in proportion as the idea of it is pleasant, is a physical and metaphysical impossibility.

So obvious does this appear to me, that I expect it will hardly be disputed: and the objection made will be, not that desire can possibly be directed to anything ultimately except pleasure and exemption from pain, but that the will is a different thing from desire; that a person of confirmed virtue, or any other person whose purposes are fixed, carries out his purposes without any thought of the pleasure he has in contemplating them, or expects to derive from their fulfilment; and persists in acting on them, even though these pleasures are much diminished, by changes in his character or decay of his passive sensibilities, or are outweighed by the pains which the pursuit of the purposes may bring upon him. All this I fully admit, and have stated it elsewhere, as positively and emphatically as any one. Will, the active phenomenon, is a different thing from desire, the state of passive sensibility, and though originally an offshoot from it, may in time take root and detach itself from the parent stock; so much so, that in case of an habitual purpose, instead of willing the thing because we desire it, we often desire it only because we will it. This, however, is but an instance of that familiar fact, the power of habit, and is nowise confined to the case of virtuous actions. Many indifferent things, which men originally did from a motive of some sort, they continue to do from habit. Sometimes this is done unconsciously, the consciousness coming only after the action: at other times with conscious volition, but volition which has become habitual, and is put into operation by the force of habit in opposition perhaps to the deliberate preference, as often happens with those who have contracted habits of vicious or hurtful indulgence. Third and last comes the case in which the habitual act of will in the individual instance is not in contradiction to the general intention prevailing at other times, but in fulfilment of it; as in the case of the person of confirmed virtue, and of all who pursue deliberately and consistently any determinate end. The distinction between will and desire thus understood, is an authentic and highly important psychological fact; but the fact consists solely in this—that will, like all other parts of our constitution, is amenable to habit, and that we may will from habit what we no longer desire for itself, or desire only because we will it. It is not the less true that will, in the beginning, is entirely produced by desire; including in that term the repelling influence of pain as well as the attractive one of pleasure. Let us take into consideration, no longer the person who has a confirmed will to do right, but him in whom that virtuous will is still feeble, conquerable by temptation, and not to be fully relied on; by what means can it be strengthened? How can the will to be virtuous, where it does not exist in sufficient force, be implanted or awakened? Only by making the person *desire* virtue—by making him think of it in a pleasurable light, or of its absence in a painful one. It is by associating the doing right with pleasure, or the doing wrong with pain, or by eliciting and impressing and bringing home to the person's experience the pleasure naturally involved in the one or the pain in the other, that it is possible to call forth that will to be virtuous, which, when confirmed, acts without any thought of either pleasure or pain. Will is the child of desire, and passes out of the dominion of its parent only to come under that of habit. That which is the result of habit affords no presumption of being intrinsically good; and there would be no reason for wishing that the purpose of virtue should become independent of pleasure and pain, were it not that the influence of the pleasurable and painful associations which prompt to virtue is not sufficiently to be depended on for unerring constancy of action until it has acquired the support of habit. Both in feeling and in conduct, habit is the only thing which imparts certainty; and it is because of the importance to others of being able to rely absolutely on one's feelings and conduct, and to oneself of being able to rely on one's own, that the will to do right ought to be cultivated into this habitual independence. In other words, this state of the will is a means to good, not intrinsically a good; and does not contradict the doctrine that nothing is a good to human beings but in so far as it is either itself pleasurable, or a means of attaining pleasure or averting pain.

But if this doctrine be true, the principle of utility is proved. Whether it is so or not, must now be left to the consideration of the thoughtful reader.

CHAPTER V.

ON THE CONNECTION BETWEEN JUSTICE AND UTILITY.

IN all ages of speculation, one of the strongest obstacles to the reception of the doctrine that Utility or Happiness is the criterion of right and wrong, has been drawn from the idea of Justice. The powerful sentiment, and apparently clear perception, which that word recalls with a rapidity and certainty resembling an instinct, have seemed to the majority of thinkers to point to an inherent quality in things; to show that the Just must have an existence in Nature as something absolute—generically distinct from every variety of the Expedient, and, in idea, opposed to it, though (as is commonly acknowledged) never, in the long run, disjoined from it in fact.

In the case of this, as of our other moral sentiments, there is no necessary connection between the question of its origin, and that of its binding force. That a feeling is bestowed on us by Nature, does not necessarily legitimate all its promptings. The feeling of justice might be a peculiar instinct, and might yet require, like our other instincts, to be controlled and enlightened by a higher reason. If we have intellectual instincts, leading us to judge in a particular way, as well as animal instincts that prompt us to act in a particular way, there is no necessity that the former should be more infallible in their sphere than the latter in theirs; it may as well happen that wrong judgments are occasionally suggested by those, as wrong actions by these. But though it is one thing to believe that we have natural feelings of justice, and another to acknowledge them as an ultimate criterion of conduct, these two opinions are very closely connected in point of fact. Mankind are always predisposed to believe that any subjective feeling, not otherwise accounted for, is a revelation of some objective reality. Our present object is to determine whether the reality, to which the feeling of justice corresponds, is one which needs any such special revelation; whether the justice or injustice of an action is a thing intrinsically peculiar, and distinct from all its other qualities, or only a combination of certain of those qualities, presented under a peculiar aspect. For the purpose of this inquiry, it is practically important to consider whether the feeling itself, of justice and injustice, is *sui generis* like our sensations of color and taste, or a derivative feeling, formed by a combination of others. And this it is the more essential to examine, as people are in general willing enough to allow, that objectively the dictates of justice coincide with a part of the field of

General Expediency; but inasmuch as the subjective mental feeling of Justice is different from that which commonly attaches to simple expediency, and, except in extreme cases of the latter, is far more imperative in its demands, people find it difficult to see, in Justice, only a particular kind or branch of general utility, and think that its superior binding force requires a totally different origin.

To throw light upon this question, it is necessary to attempt to ascertain what is the distinguishing character of justice, or of injustice: what is the quality, or whether there is any quality, attributed in common to all modes of conduct designated as unjust (for justice, like many other moral attributes, is best defined by its opposite), and distinguishing them from such modes of conduct as are disapproved, but without having that particular epithet of disapprobation applied to them. If, in everything which men are accustomed to characterize as just or unjust, some one common attribute or collection of attributes is always present, we may judge whether this particular attribute or combination of attributes would be capable of gathering round it a sentiment of that peculiar character and intensity by virtue of the general laws of our emotional constitution, or whether the sentiment is inexplicable, and requires to be regarded as a special provision of Nature. If we find the former to be the case, we shall, in resolving this question, have resolved also the main problem: if the latter, we shall have to seek for some other mode of investigating it.

To find the common attributes of a variety of objects, it is necessary to begin by surveying the objects themselves in the concrete. Let us therefore advert successively to the various modes of action, and arrangements of human affairs, which are classed, by universal or widely spread opinion, as Just or as Unjust. The things well known to excite the sentiments associated with those names, are of a very multifarious character. I shall pass them rapidly in review, without studying any particular arrangement.

In the first place, it is mostly considered unjust to deprive any one of his personal liberty, his property, or any other thing which belongs to him by law. Here, therefore, is one instance of the application of the terms just and unjust in a perfectly definite sense, namely, that it is just to respect, unjust to violate, the *legal rights* of any one. But this judgment admits of several exceptions, arising from the other forms in which the notions of justice and injustice present themselves. For example, the person who suffers the deprivation may (as the phrase is) have *forfeited* the rights which he is so deprived of: a case to which we shall return presently. But also,

Secondly; the legal rights of which he is deprived, may be rights which *ought* not to have belonged to him; in other words, the law which confers on him these rights, may be a bad law. When it is so, or when (which is the same thing for our purpose) it is supposed to be so, opinions will differ as to the justice or injustice of infringing it. Some maintain that no law, however bad, ought to be disobeyed by an individual citizen; that his opposition to it, if shown at all, should only be shown in endeavoring to get it altered by competent authority. This opinion (which condemns many of the most illustrious benefactors of mankind, and would often protect pernicious institutions against the only weapons which, in the state of things existing at the time, have any chance of succeeding against them) is defended, by those who hold it, on grounds of expediency; principally on that of the importance, to the common interest of mankind, of maintaining inviolate the sentiment of submission to law. Other persons, again hold the directly contrary opinion, that any law, judged to be bad, may blamelessly be disobeyed, even though it be not judged to be unjust, but only inexpedient; while others would confine the licence of disobedience to the case of unjust laws: but again, some say, that all laws which are inexpedient are unjust; since every law imposes some restriction on the natural liberty of mankind, which restriction is an injustice, unless legitimated by tending to their good. Among these diversities of opinion, it seems to be universally admitted that there may be unjust laws, and that law, consequently, is not the ultimate criterion of justice, but may give to one person a benefit, or impose on another an evil, which justice condemns. When, however, a law is thought to be unjust, it seems always to be regarded as being so in the same way in which a breach of law is unjust, namely, by infringing somebody's right; which, as it cannot in this case be a legal right, receives a different appellation, and is called a moral right. We may say, therefore, that a second case of injustice consists in taking or withholding from any person that to which he has a *moral right.*

Thirdly, it is universally considered just that each person should obtain that (whether good or evil) which he *deserves;* and unjust that he should obtain a good, or be made to undergo an evil, which he does not deserve. This is, perhaps, the clearest and most emphatic form in which the idea of justice is conceived by the general mind, As it involves the notion of desert, the question arises, what constitutes desert? Speaking in a general way, a person is understood to deserve good if he does right, evil if he does wrong; and in a more particular sense, to deserve good from those to whom he does or has done good, and evil from those to whom he does or has done evil. The precept of returning good for evil has never been regarded as a case of the fulfilment of justice, but as one in which the claims of justice are waived, in obedience to other considerations.

Fourthly, it is confessedly unjust to *break faith* with any one: to violate an engagement, either expressed or implied, or disappoint expectations raised by our own conduct, at least if we have raised those expectations knowingly and voluntarily. Like the other obligations of justice already spoken of, this one is not regarded as absolute, but as capable of being overruled by a stronger obligation of justice on the other side; or by such conduct on the part of the person concerned as is deemed to absolve us from our obligation to him, and to constitute a *forfeiture* of the benefit which he has been led to expect.

Fifthly, it is, by universal admission, inconsistent with justice to be *partial;* to show favor or preference to one person over another, in matters to which favor and preference do not properly apply. Impartiality, however, does not seem to be regarded as a duty in itself, but rather as instrumental to some other duty; for it is admitted that favor and preference are not always censurable, and indeed the cases in which they are condemned are rather the exception than the rule. A person would be more likely to be blamed than applauded for giving his family or friends no superiority in good offices over strangers, when he could do so without violating any other duty; and no one thinks it unjust to seek one person in preference to another as a friend, connection, or companion. Impartiality where rights are concerned is of course obligatory, but this is involved in the more general obligation of giving to every one his right. A tribunal, for example, must be impartial, because it is bound to award, without regard to any other consideration, a disputed object to the one of two parties who has the right to it. There are other cases in which impartiality means, being solely influenced by desert; as with those who, in the capacity of judges, preceptors, or parents, administer reward and punishment as such. There are cases, again, in which it means being solely influenced by consideration for the public interest; as in making a selection among candidates for a Government employment. Impartiality, in short, as an obligation of justice, may be said to mean being exclusively influenced by the considerations which it is supposed ought to influence the particular case in hand; and resisting the solicitation of any motives which prompt to conduct different from what those considerations would dictate.

Nearly allied to the idea of impartiality, is that of *equality;* which often enters as a component part both into the conception of justice and into the practice of it, and, in the eyes of many persons, constitutes its essence. But in this, still more than in any other case, the notion of justice varies in different persons, and always conforms in its variations to their notion of utility. Each person maintains that equality is the dictate of justice, except where he thinks that expediency requires inequality. The justice of giving equal protection to the rights of all, is maintained by those who support the most outrageous inequality in the rights themselves. Even in slave countries it is theoretically admitted that the rights of the slave, such as they are, ought to be as sacred as those of the master; and that a tribunal which fails to enforce them with equal strictness is wanting in justice; while, at the same time, institutions which leave to the slave scarcely any rights to enforce, are not deemed unjust, because they are not deemed inexpedient. Those who think that utility requires distinctions of rank, do not consider it unjust that riches and social privileges should be unequally dispensed; but those who think this inequality inexpedient, think it unjust also. Whoever thinks that government is necessary, sees no injustice in as much inequality as is constituted by giving to the magistrate powers not granted to other people. Even among those who hold leveling doctrines, there are as many questions of justice as there are differences of opinion about expediency. Some Communists consider it unjust that the produce of the labor of the community should be shared on any other principle than that of exact equality; others think it just that those should receive most whose needs are greatest; while others hold that those who work harder, or who produce more, or whose services are more valuable to the community, may justly claim a larger quota in the division of the produce. And the sense of natural justice may be plausibly appealed to in behalf of every one of these opinions.

Among so many diverse applications of the term Justice, which yet is not regarded as ambiguous, it is a matter of some difficulty to seize the mental link which holds them together, and on which the moral sentiment adhering to the term essentially depends. Perhaps, in this embarrassment, some help may be derived from the history of the word, as indicated by its etymology.

In most, if not in all, languages, the etymology of the word which corresponds to Just, points to an origin connected either with positive law, or with that which was in most cases the primitive form of law—authoritative custom. *Justum* is a form of *jussum*, that which has been ordered. *Jus* is of the same origin. Δίκαιον comes from δίκη, of which the principal meaning, at least in the historical ages of Greece, was a suit at law. Originally, indeed, it meant only the mode or *manner* of doing things, but it early came to mean the *prescribed* manner; that which the recognized authorities, patriarchal, judicial, or political, would enforce. *Recht*, from which came *right* and *righteous*, is synonymous with law. The original meaning, indeed, of *recht* did not point to law, but to physical straightness; as *wrong* and its Latin equivalents meant twisted or *tortuous;* and from this it is argued that right did not originally mean law, but on the contrary law meant right. But however this may be, the fact that *recht* and *droit* became restricted in their meaning to positive law, although much which is not required by law is equally necessary to moral straightness or rectitude, is as significant of the original character of moral ideas as if the derivation had been the reverse way. The courts of justice, the administration of justice, are the courts and the administration of law. *La justice*, in French, is the established term for judicature. There can, I think, be no doubt that the *idée mère*, the primitive element, in the formation of the notion of justice, was conformity to law. It constituted the entire idea among the Hebrews, up to the birth of Christianity; as might be expected in the case of a people whose laws attempted to embrace all subjects on which precepts were required, and who believed those laws to be a direct emanation from the Supreme Being. But other nations, and in particular the Greeks and Romans, who knew that their laws had been made originally, and still continued to be made, by men, were not afraid to admit that those men might make bad laws; might do, by law, the same things, and from the same motives, which, if done by individuals, without the sanction of law, would be called unjust. And hence the sentiment of injustice came to be attached, not to all violations of law, but only to violations of such laws as *ought* to exist, including such as ought to exist but do not: and to laws themselves, if supposed to be contrary to what ought to be law. In this manner the idea of law and of its injunctions was still predominant in the notion of justice, even when the laws actually in force ceased to be accepted as the standard of it.

It is true that mankind consider the idea of justice and its obligations as applicable to many things which neither are, nor is it desired that they should be, regulated by law. Nobody desires that laws should interfere with the whole detail of private life; yet every one allows that in all daily conduct a person may and does show himself to be either just or unjust. But even here, the idea of the breach of what ought to be law, still lingers in a modified shape. It would always give us pleasure, and chime in with our feelings of fitness, that acts which we deem unjust should be punished, though we do not always think it expedient that this should be done by the tribunals. We forego that gratification on account of incidental inconveniences. We should be glad to see just conduct enforced and injustice repressed, even in the minutest details, if we were not, with reason, afraid of trusting the magistrate with so unlimited an amount of power over individuals. When we think that a person is bound in justice to do a thing, it is an ordinary form of language to say, that he ought to be compelled to do it. We should be gratified to see the obligation enforced by anybody who had the power. If we see that its enforcement by law would be inexpedient, we lament the impossibility, we consider the impunity given to injustice as an evil, and strive to make amends for it by bringing a strong expression of our own and the public disapprobation to bear upon the offender. Thus the idea of legal constraint is still the generating idea of the notion of justice, though undergoing several transformations before that notion, as it exists in an advanced state of society, becomes complete.

The above is, I think, a true account, as far as it goes, of the origin and progressive growth of the idea of justice. But we must observe, that it contains, as yet, nothing to distinguish that obligation from moral obligation in general. For the truth is, that the idea of penal sanction, which is the essence of law, enters not only into the conception of injustice, but into that of any kind of wrong. We do not call anything wrong, unless we mean to imply that a person ought to be punished in some way or other for doing it; if not by law, by the opinion of his fellow creatures; if not by opinion, by the reproaches of his own conscience. This seems the real turning point of the distinction between morality and simple expediency. It is a part of the notion of Duty in every one of its forms, that a person may rightfully be compelled to fulfil it. Duty is a thing which may be *exacted* from a person, as one exacts a debt. Unless we think that it might be exacted from him, we do not call it his duty. Reasons of prudence, or the interest of other people, may militate against actually exacting it; but the person himself, it is clearly understood, would not be entitled to complain. There are other things, on the contrary, which we wish that people should do, which we like or admire them for doing, perhaps dislike or despise them for not doing, but yet admit that they are not bound to do: it is not a case of moral obligation; we do not blame them, that is, we do not think that they are proper objects of punishment. How we come by these ideas of deserving and not deserving punishment, will appear, perhaps, in the sequel; but I think there is no doubt that this distinction lies at the bottom of the notions of right and wrong; that we call any conduct wrong, or employ instead, some other term of dislike or disparagement, according as we think that the person ought, or ought not, to be punished for it: and we say that it would be right to do so and so, or merely that it would be desirable or laudable, according as we would wish to see the person whom it concerns, compelled or only persuaded and exhorted, to act in that manner.*

This, therefore, being the characteristic difference which marks off, not justice, but morality in general, from the remaining provinces of Expediency and Worthiness; the character is still to be sought which distinguishes justice from other branches of morality. Now it is known that ethical writers divide moral duties into two classes, denoted by the ill-chosen expressions, duties of perfect and of imperfect obligation; the latter being those in which, though the act is obligatory, the particular occasions of performing it are left to our choice; as in the case of charity or beneficence, which we are indeed bound to practice, but not towards any definite person, nor at any prescribed time. In the more precise language of philosophic jurists, duties of

* See this point enforced and illustrated by Professor Bain in an admirable chapter (entitled "The Ethical Emotions, or the Moral Sense"), of the second of the two treatises composing his elaborate and profound work on the Mind,

perfect obligation are those duties in virtue of which a correlative *right* resides in some person or persons; duties of imperfect obligation are those moral obligions which do not give birth to any right. I thing it will be found that this distinction exactly coincides with that which exists between justice and the other obligations of morality. In our survey of the various popular acceptations of justice, the term appeared generally to involve the idea of a personal right—a claim on the part of one or more individuals, like that which the laws gives when it confers a proprietary or other legal right. Whether the injustice consists in depriving a person of a possession, or in breaking faith with him, or in treating him worse than he deserves, or worse than other people who have no greater claims, in each case the supposition implies two things—a wrong done, and some assignable person who is wronged. Injustice may also be done by treating a person better than others; but the wrong in this case is to his competitors, who are also assignable persons. It seems to me that this feature in the case—a right in some person, correlative to the moral obligation—constitutes the specific difference between justice, and generosity or beneficence. Justice implies something which it is not only right to do, and wrong not to do, but which some individual person can claim from us as his moral right. No one has a moral right to our generosity or beneficence, because we are not morally bound to practice those virtues towards any given individual. And it will be found, with respect to this as with respect to every correct definition, that the instances which seem to conflict with it are those which most confirm it. For if a moralist attempts, as some have done, to make out that mankind generally, though not any given individual, have a right to all the good we can do to them, he at once, by that thesis, includes generosity and beneficence within the category of justice. He is obliged to say, that our utmost exertions are *due* to our fellow creatures, thus assimilating them to a debt; or that nothing less can be a sufficient *return* for what society does for us, thus classing the case as one of gratitude both of which are acknowledged cases of justice. Wherever there is a right the case is one of justice, and not of the virtue of beneficence: and whoever does not place the distinction between justice and morality in general where we have now placed it, will be found to make no distinction between them at all, but to merge all morality in justice.

Having thus endeavored to determine the distinctive elements which enter into the composition of the idea of justice, we are ready to enter on the inquiry, whether the feeling, which accompanies the idea, is attached to it by a special dispensation of nature, or whether it could have grown up, by any known laws, out of the idea itself; and in particular, whether it can have originated in considerations of general expediency.

I conceive that the sentiment itself does not arise from anything which would commonly, or correctly, be termed an idea of expediency; but that though the sentiment does not, whatever is moral in it does.

We have seen that the two essential ingredients in the sentiment of justice are, the desire to punish a person who has done harm, and the knowledge or belief that there is some definite individual or individuals to whom harm has been done.

Now it appears to me, that the desire to punish a person who has done harm to some individual, is a spontaneous outgrowth from two sentiments, both in the highest degree natural, and which either are or resemble instincts; the impulse of self-defence, and the feeling of sympathy.

It is natural to resent, and to repel or retaliate, any harm done or attempted against ourselves, or against those with whom we sympathize. The origin of this sentiment it is not necessary here to discuss. Whether it be an instinct or a result of intelligence, it is, we know, common to all animal nature; for every animal tries to hurt those who have hurt, or who it thinks are about to hurt, itself or its young. Human beings, on this point, only differ from other animals in two particulars. First, in being capable of sympathizing, not solely with their offspring, or, like some of the more noble animals, with some superior animal who is kind to them, but with all human, and even with all sentient, beings. Secondly, in having a more developed intelligence, which gives a wider range to the whole of their sentiments, whether self-regarding or sympathetic. By virtue of his superior intelligence, even apart from his superior range of sympathy, a human being is capable of apprehending a community of interest between himself and the human society of which he forms a part, such that any conduct which threatens the security of the society generally, is threatening to his own, and calls forth his instinct (if instinct it be) of self-defence. The same superiority of intelligence, joined to the power of sympathizing with human beings generally, enables him to attach himself to the collective idea of his tribe, his country, or mankind, in such a manner that any act hurtful to them rouses his instinct of sympathy, and urges him to resistance.

The sentiment of justice, in that one of its elements which consists of the desire to punish, is thus, I conceive, the natural feeling of retaliation or vengeance, rendered by intellect and sympathy applicable to those injuries, that is, to those hurts which wound us through, or in common with, society at large. This sentiment, in itself, has nothing moral in it; what is moral is the exclusive subordination of it to the social sympathies, so as to wait on and obey their call. For the natural feeling tends to make us resent indiscriminately whatever any one does that is disagreeable to us; but when moralized by the social feeling, it only acts in the directions conformable to the general good; just persons resenting a hurt to society, though not otherwise a hurt to themselves, and not resenting a hurt to themselves, however painful, unless it be of the kind which society has a common interest with them in the repression of.

It is no objection against this doctrine to say, that when we feel our sentiment of justice outraged, we are not thinking of society at large, or of any collective interest, but only of the individual case. It is common enough certainly, though the reverse of commendable, to feel resentment merely because we have suffered pain; but a person whose resentment is really a moral feeling, that is, who considers whether an act is blameable before he allows himself to resent it—such a person, though he may not say expressly to himself that he is standing up for the interest of society, certainly does feel that he is asserting a rule which is for the benefit of others as well as for his own. If he is not feeling this—if he is regarding the act solely as it affects him individually—he is not consciously just; he is not concerning himself about the justice of his actions. This is admitted even by anti-utilitarian moralists. When Kant (as before remarked) propounds as the fundamental principle of morals, "So act, that thy rule o conduct might be adopted as a law by all rational beings," he virtually acknowledges that the interest of mankind collectively, or at least of mankind indiscriminately, must be in the mind of the agent when conscientiously deciding on the morality of the act. Otherwise he uses words without a meaning; for, that a rule even of utter selfishness could not *possibly* be adopted by all rational beings—that there is any insuperable obstacle in the nature of things to its adoption—cannot be even plausibly maintained. To give any meaning to Kant's principle, the sense put upon it must be, that we ought to shape our conduct by a rule which all rational beings might adopt *with benefit to their collective interest.*

To recapitulate; the idea of justice supposes two things; a rule of conduct, and a sentiment which sanctions the rule. The first must be supposed common to all mankind, and intended for their good. The other (the sentiment) is a desire that punishment may be suffered by those who infringe the rule. There is involved, in addition, the conception of some definite person who suffers by the infringement; whose rights (to use the expression appropriated to the case) are violated by it. And the sentiment of justice appears to me to be, the animal desire to repel or retaliate a hurt or damage to oneself, or to those with whom one sympathizes, widened so as to include all persons, by the human capacity of enlarged sympathy, and the human conception of intelligent self-interest. From the latter elements, the feeling derives its morality; from the former, its peculiar impressiveness, and energy of self-assertion.

I have, throughout, treated the idea of a *right* residing in the injured person, and violated by the injury, not as a separate element in the composition of the idea and sentiment, but as one of the forms in which the other two elements clothe themselves. These elements are, a hurt to some assignable person or persons on the one hand, and a demand for punishment on the other. An examination of our own minds, I think, will show, that these two things include all that we mean when we speak of violation of a right. When we call anything a person's right, we mean that he has a valid claim on society to protect him in the possession of it, either by the force of law, or by that of education and opinion. If he has what we consider a sufficient claim, on whatever account, to have something guaranteed to him by society, we say that he has a right to it. If we desire to prove that anything does not belong to him by right, we think this done as soon as it is admitted that society ought not to take measures for securing it to him, but should leave it to chance, or to his own exertions. Thus, a person is said to have a right to what he can earn in fair professional competition; because society ought not to allow any other person to hinder him from endeavoring to earn in that manner as much as he can. But he has not a right to three hundred a-year, though he may happen to be earning it; because society is not called on to provide that he shall earn that sum. On the contrary, if he owns ten thousand pounds three per cent. stock he *has* a right to three hundred a-year; because society has come under an obligation to provide him with an income of that amount.

To have a right, then, is, I conceive, to have something which society ought to defend me in the possession of. If the objector goes on to ask why it ought, I can give him no other reason than general utility. If that expression does not seem to convey a sufficient feeling of the strength of the obligation, nor to account for the peculiar energy of the feeling, it is because there goes to the composition of the sentiment, not a rational only but also an animal element, the thirst for retaliation; and this thirst derives its intensity, as well as its moral justification, from the extraordinarily important and impressive kind of utility which is concerned. The interest involved is that of security, to every one's feelings the most vital of all interests. Nearly all other earthly benefits are needed by one person, not needed by another; and many of them can, if necessary, be cheerfully foregone, or replaced by something else; but security no human being can possibly do without; on it we depend for all our immunity from evil, and for the whole value of all and every good, beyond the passing moment; since nothing but the gratification of the instant could be of any worth to us, if we could be deprived of everything the next instant by whoever was momentarily stronger than ourselves. Now this most indispensable of all necessaries, after physical nutriment, cannot be had, unless the machinery for providing it is kept unintermittedly in active play. Our notion, therefore, of the claim we have on our fellow creatures to join in making safe for us the very groundwork of our existence, gathers feelings round it so much more intense than those concerned in any of the more common cases of utility, that the difference in degree (as is often the case in psychology) becomes a real difference in kind. The claim assumes that character of absoluteness, that apparent infinity, and incommensurability with all other considerations, which constitute the distinction between the feeling of right and wrong and that of ordinary expediency and inexpediency. The feelings concerned are so powerful, and we count so positively on finding a responsive feeling in others (all being alike interested), that *ought* and *should* grow into *must*, and recognized indispensability becomes a moral necessity, analogous to physical, and often not inferior to it in binding force.

If the preceding analysis, or something resembling it, be not the correct account of the notion of justice; if justice be totally independent of utility, and be a standard *per se*, which the mind can recognize by simple introspection of itself; it is hard to understand why that internal oracle is so ambiguous, and why so many things appear either just or unjust, according to the light in which they are regarded.

We are continually informed that Utility is an uncertain standard, which every different person interprets differently, and that there is no safety but in the immutable, ineffaceable, and unmistakable dictates of Justice, which carry their evidence in themselves, and are independent of the fluctuations of opinion. One would suppose from this that on questions of justice there could be no controversy; that if we take that for our rule, its application to any given case could leave us in as little doubt as a mathematical demonstration. So far is this from being the fact, that there is as much difference of opinion, and as fierce discussion, about what is just, as about what is useful to society. Not only have different nations and individuals different notions of justice, but, in the mind of one and the same individual, justice is not some one rule, principle, or maxim, but many, which do not always coincide in their dictates, and in choosing between which, he is guided either by some extraneous standard, or by his own personal predilections.

For instance, there are some who say, that it is unjust to punish anyone for the sake of example to others; that punishment is just, only when intended for the good of the sufferer himself. Others maintain the extreme reverse, contending that to punish persons who have attained years of discretion, for their own benefit, is despotism and injustice, since if the matter at issue is solely their own good, no one has a right to control their own judgment of it; but that they may justly be punished to prevent evil to others, this being an exercise of the legitimate right of self-defence. Mr. Owen, again, affirms that it is unjust to punish at all; for the criminal did not make his own character; his education, and the circumstances which surround him, have made him a criminal, and for these he is not responsible. All these opinions are extremely plausible; and so long as the question is argued as one of justice simply, without going down to the principles which lie under justice and are the source of its authority, I am unable to see how any of these reasoners can be refuted. For, in truth, every one of the three builds upon rules of justice confessedly true. The first appeals to the acknowledged injustice of singling out an individual, and making him a sacrifice, without his consent, for other people's benefit. The second relies on the acknowledged justice of self-defence, and the admitted injustice of forcing one person to conform to another's notions of what constitutes his good. The Owenite invokes the admitted principle, that it is unjust to punish any one for what he cannot help. Each is triumphant so long as he is not compelled to take into consideration any other maxims of justice than the one he has selected; but as soon as their several maxims are brought face to face, each disputant seems to have exactly as much to say for himself as the others. No one of them can carry out his own notion of justice without trampling upon another equally binding. These are difficulties; they have always been felt to be such; and many devices have been invented to turn rather than to overcome them. As a refuge from the last of the three, men imagined what they called the freedom of the will; fancying that they could not justify punishing a man whose will is in a thoroughly hateful state, unless it be supposed to have come into that state through no influence of anterior circumstances. To escape from the other difficulties, a favorite contrivance has been the fiction of a contract, whereby at some unknown period all the members of society engaged to obey the laws, and consented to be punished for any disobedience to them; thereby giving to their legislatures the right, which it is assumed they would not otherwise have had, of punishing them, either for their own good or for that of society. This happy thought was considered to get rid of the whole difficulty, and to legitimate the infliction of punishment, in virtue of another received maxim of justice, *volenti non fit injuria;* that is not unjust which is done with the consent of the person who is supposed to be hurt by it. I need hardly remark, that even if the consent were not a mere fiction, this maxim is not superior in authority to the others which it is brought in to supersede. It is, on the contrary, an instructive specimen of the loose and irregular manner in which supposed principles of justice grow up. This particular one evidently came into use as a help to the coarse exigencies of courts of law, which are sometimes obliged to be content with very uncertain presumptions, on account of the greater evils which would often arise from many attempt on their part to cut finer. But even courts of law are not able to adhere consistently to the maxim, for they allow voluntary engagements to be set aside on the ground of fraud; and sometimes on that of mere mistake or misinformation.

Again, when the legitimacy of inflicting punishment is admitted, how many conflicting conceptions of justice come to light in discussing the proper apportionment of punishment to offences. No rule on this subject recommends itself so strongly to the primitive and spontaneous sentiment of justice, as the *lex talionis*, an eye for an eye and a tooth for a tooth. Though this principle of the Jewish and of the Mahomedan law has been generally abandoned in Europe as a practical maxim, there is, I suspect, in most minds, a secret hankering after it; and when retribution accidentally falls on an offender in that precise shape, the general feeling of satisfaction evinced, bears witness how natural is the sentiment to which this repayment in kind is acceptable. With many the test of justice in penal infliction is that the punishment should be proportioned to the offence; meaning that it should be exactly measured by the moral guilt of the culprit (whatever be their standard for measuring moral guilt): the consideration, what amount of punishment is necessary to deter from the offence, having nothing to do with the question of justice, in their estimation: while there are others to whom that consideration is all in all: who maintain that it is not just, at least for man, to inflict on a fellow creature, whatever may be his offences, any amount of suffering beyond the least that will suffice to prevent him from repeating, and others from imitating, his misconduct.

To take another example from a subject already once referred to. In a co-operative industrial association, is it just or not that talent or skill should give a title to superior remuneration? On the negative side of the question it is argued, that whoever does the best he can, deserves equally well, and ought not in justice to be put in a position of inferiority for no fault of his own; that superior abilities have already advantages more than enough, in the admiration they excite, the personal influence they command, and the internal sources of satisfaction attending them, without adding to these a superior share of the world's goods; and that society is bound in justice rather to make compensation to the less favored, for this unmerited inequality of advantages, than to aggravate it. On the contrary side it is contended, that society receives more from the more efficient laborer; that his services being more useful, society owes him a larger return for them; that a greater share of the joint result is actually his work, and not to allow his claim to it is a kind of robbery; that if he is only to receive as much as others, he can only be justly required to produce as much, and to give a smaller amount of time and exertion, proportioned to his superior efficiency. Who shall decide between these appeals to conflicting principles of justice? Justice has in this case two sides to it, which it is impossible to bring into harmony, and the two disputants have chosen opposite sides; the one looks to what it is just that the individual should receive, the other to what it is just that the community should give. Each, from his own point of view, is unanswerable; and any choice between them, on grounds of justice, must be perfectly arbitrary. Social utility alone can decide the preference.

How many, again, and how irreconcilable, are the standards of justice to which reference is made in discussing the repartition of taxation. One opinion is, that payment to the State should be in numerical proportion to pecuniary means. Others think that justice dictates what they term graduated taxation; taking a higher percentage from those who have more to spare. In point of natural justice a strong case might be made for disregarding means altogether, and taking the same absolute sum (whenever it could be got) from every one: as the subscribers to a mess, or to a club, all pay the same sum for the same privileges, whether they can all equally afford it or not. Since the protection (it might be said) of law and government is afforded to, and is equally required by, all, there is no injustice in making all buy it at the same price. It is reckoned justice, not injustice, that a dealer should charge to all customers the same price for the same article, not a price varying according to their means of payment. This doctrine, as applied to taxation, finds no advocates, because it conflicts strongly with men's feelings of humanity and perceptions of social expediency; but the principle of justice which it invokes is as true and as binding as those which can be appealed to against it. Accordingly, it exerts a tacit influence on the line of defence employed for other modes of assessing taxation. People feel obliged to argue that the State does more for the rich than for the poor, as a justification for its taking more from them: though this is in reality not true, for the rich would be far better able to protect themselves, in the absence of law or government, than the poor, and indeed would probably be successful in converting the poor into their slaves. Others, again, so far defer to the same conception of justice, as to maintain that all should pay an equal capitation tax for the protection of their persons (these being of equal value to all) and an unequal tax for the protection of their property, which is unequal. To this others reply, that the all of one man is as valuable to him as the all of another. From these confusions there is no other mode of extrication than the utilitarian.

Is, then, the difference between the Just and the Expedient a merely imaginary distinction? Have mankind been under a delusion in thinking that justice is a more sacred thing than policy, and that the latter ought only to be listened to after the former has been satisfied? By no means. The exposition we have given of the nature and origin of the sentiment, recognizes a real distinction; and no one of those who profess the most sublime contempt for the consequences of actions as an element in their morality, attaches more importance to the distinction than I do. While I dispute the pretentions of any theory which sets up an imaginary standard of justice not grounded on utility, I account the justice which is grounded on utility to be the chief part, and incomparably the most sacred and binding part, of all morality. Justice is a name for certain classes of moral rules, which concern the essentials of human well-being more nearly, and are therefore of more absolute obligation, than any other rules for the guidance of life; and the notion which we have found to be of the essence of the idea of justice, that of a right residing in an individual, implies and testifies to this more binding obligation.

The moral rules which forbid mankind to hurt one another (in which we must never forget to include wrongful interference with each other's freedom) are more vital to human well-being than any maxims, however important, which only point out the best mode of managing some department of human affairs. They have also the peculiarity, that they are the main element in determining the whole of the social feelings of mankind. It is their observance which alone preserves peace among human beings: if obedience to them were not the rule, and disobedience the exception, every one would see in every one else a probable enemy, against whom he must be perpetually guarding himself. What is hardly less important, these are the precepts which mankind have the strongest and the most direct inducements for impressing upon one another. By merely giving to each other prudential instruction or exhortation, they may gain, or think they gain, nothing: in inculcating on each other the duty of positive beneficence they have an unmistakable interest, but far less in degree: a person may possibly not need the benefits of others; but he always needs that they should not do him hurt. Thus the moralities which protect every individual from being harmed by others, either directly or by being hindered in his freedom of pursuing his own good, are at once those which he himself has most at heart, and those which he has the strongest interest in publishing and enforcing by word and deed. It is by a person's observance of these, that his fitness to exist as one of the fellowship of human beings, is tested and decided; for on that depends his being a nuisance or not to those with whom he is in contact. Now it is these moralities primarily, which compose the obligations of justice. The most marked cases of injustice, and those which give the tone to the feeling of repugnance which characterizes, the sentiment, are acts of wrongful aggression, or wrongful exercise of power over some one; the next are those which consist in wrongfully withholding from him something which is his due; in both cases, inflicting on him a positive hurt, either in the form of direct suffering, or of the privation of some good which he had reasonable ground, either of a physical or of a social kind, for counting upon.

The same powerful motives which command the observance of these primary moralities, enjoin the punishment of those who violate them; and as the impulses of self-defence, of defence of others, and of vengeance, are all called forth against such persons, retribution, or evil for evil, becomes closely connected with the sentiment of justice, and is universally included in the idea. Good for good is also one of the dictates of justice; and this, though its social utility is evident, and though it carries with it a natural human feeling, has not at first sight that obvious connection with hurt or injury, which, existing in the most elementary cases of just and unjust, is the source of the characteristic intensity of the sentiment. But the connection, though less obvious, is not less real. He who accepts benefits, and denies a return of them when needed, inflicts a real hurt, by disappointing one of the most natural and reasonable of expectations, and one which he must at least tacitly have encouraged, otherwise the benefits would seldom have been conferred. The important rank, among human evils and wrongs, of the disappointment of expectation, is shown in the fact that it constitutes the principal criminality or two such highly immoral acts as a breach of friendship and a breach of promise. Few hurts which human beings can sustain are greater, and none wound more, than when that on which they habitually and with full assurance relied, fails them in the hour of need; and few wrongs are greater than this mere withholding of good; none excite more resentment, either in the person suffering, or in a sympathizing spectator. The principle, therefore, of giving to each what they deserve, that is, good for good as well as evil for evil, is not only included within the idea of Justice as we have defined it, but is a proper object of that intensity of sentiment, which places the Just, in human estimation, above the simply Expedient.

Most of the maxims of justice current in the world, and commonly appealed to in its transactions, are simply instrumental to carrying into effect the principles of justice which we have now spoken of. That a person is only responsible for what he has done voluntarily, or could voluntarily have avoided; that it is unjust to condemn any person unheard; that the punishment ought to be proportioned to the offence, and the like, are maxims intended to prevent the just principle of evil for evil from being perverted to the infliction of evil without that justification. The greater part of these common maxims have come into use from the practice of courts of justice, which have been naturally led to a more complete recognition and elaboration than was likely to suggest itself to others, of the rules necessary to enable them to fulfil their double function, of inflicting punishment when due, and of awarding to each person his right.

That first of judicial virtues, impartiality, is an obligation of justice, partly for the reason last mentioned; as being a necessary condition of tne fulfilment of the other obligations of justice. But this is not the only source of the exalted rank, among human obligations, of those maxims of equality and impartiality, which, both in popular estimation and in that of the most enlightened, are included among the precepts of justice. In one point of view, they may be considered as corollaries from the principles already laid down. If it is a duty to do to each according to its deserts, returning good for good as well as repressing evil by evil, it necessarily follows that we should treat all equally well (when no higher duty forbids) who have deserved equally well of us, and that society should treat all equally well who have deserved equally well of it, that is, who have deserved equally well absolutely. This is the highest abstract standard of social and distributive justice; towards which all institutions, and the efforts of all virtuous citizens, should be made in the utmost possible degree to converge. But this great moral duty rests upon a still deeper foundation, being a direct emanation from the first principles of morals, and not a mere logical corollary from secondary or derivative doctrines. It is involved in the very meaning of Utility, or the Greatest-Happiness Principle. That principle is a mere form of words without rational signification, unless one person's happiness, supposed equal in degree (with the proper allowance made for kind), is counted for exactly as much as another's. Those conditions being supplied, Bentham's dictum, "everybody to count for one, nobody for more than one," might be written under the principle of utility as an explanatory commentary.* The equal claim of everybody to happiness in the estimation of the moralist and the legislator, involves an equal claim to all the means of happiness, except in so far as the inevitable conditions of human life, and the general interest, in which that of every individual is included, set limits to the maxim; and those limits ought to be strictly construed. As every other maxim of justice, so this, is by no means

* This implication, in the first principle of the utilitarian scheme, of perfect impartiality between persons, is regarded by Mr. Herbert Spencer (in his *Social Statics*) as a disproof of the pretentions of utility to be a sufficient guide to right; since (he says) the principle of utility presupposes the anterior principle, that everybody has an equal right to happiness. It may be more correctly described as supposing that equal amounts of happiness are equally desirable, whether felt by the same or by different persons. This, however, is not a presupposition; not a premise needful to support the principle of utility, but the very principle itself; for what is the principle of utility, if it be not that "happiness" and "desirable" are synonymous terms? If there is any anterior principle implied, it can be no other than this, that the truths of arithmetic are applicable to the valuation of happiness, as of all other measurable quantities.

[Mr. Herbert Spencer, in a private communication on the subject of the preceding Note, objects to being considered an opponent of Utilitarianism, and states that he regards happiness as the ultimate end of morality; but deems that end only partially attainable by empirical generalizations from the observed results of conduct, and completely attainable only by deducing, from the laws of life and the conditions of existence, what kinds of action necessarily tend to produce happiness, and what kinds to produce unhappiness. With the exception of the word "necessarily," I have no dissent to express from this doctrine; and (omitting that word) I am not aware that any modern advocate of utilitarianism is of a different opinion. Bentham, certainly, to whom in the *Social Statics* Mr. Spencer particularly referred, is, least of all writers, chargable with unwillingness to deduce the effect of actions on happiness from the laws of human nature and the universal conditions of human life. The common charge against him is of relying too exclusively upon such deductions, and declining altogether to be bound by the generalizations from specific experience which Mr. Spencer thinks that utilitarians generally confine themselves to. My own opinion (and, as I collect, Mr. Spencer's) is, that in ethics, as in all other branches of scientific study, the consilience of the results of both these processes, each corroborating and verifying the other, is requisite to give to any general proposition the kind and degree of evidence which constitutes scientific proof.]

applied or held applicable universally; on the contrary, as I have already remarked, it bends to every person's ideas of social expediency. But in whatever case it is deemed applicable at all, it is held to be the dictate of justice. All persons are deemed to have a *right* to equality of treatment, except when some recognized social expediency requires the reverse. And hence all social inequalities which have ceased to be considered expedient, assume the character not of simple inexpediency, but of injustice, and appear so tyrannical, that people are apt to wonder how they ever could have been tolerated; forgetful that they themselves perhaps tolerate other inequalities under an equally mistaken notion of expediency, the correction of which would make that which they approve seem quite as monstrous as what they have at last learnt to condemn. The entire history of social improvement has been a series of transitions, by which one custom or institution after another, from being a supposed primary necessity of social existence, has passed into the rank of an universally stigmatized injustice and tyranny. So it has been with the distinctions of slaves and freemen, nobles and serfs, patricians and plebeians; and so it will be, and in part already is, with the aristocracies of color, race, and sex.

It appears from what has been said, that justice is a name for certain moral requirements, which, regarded collectively, stand higher in the scale of social utility, and are therefore of more paramount obligation, than any others; though particular cases may occur in which some other social duty is so important, as to overrule any one of the general maxims of justice. Thus, to save a life, it may not only be allowable, but a duty, to steal, or take by force, the necessary food or medicine, or to kidnap, and compel to officiate, the only qualified medical practitioner. In such cases, as we do not call anything justice which is not a virtue, we usually say, not that justice must give way to some other moral principle, but that what is just in ordinary cases is, by reason of that other principle, not just in the particular case. By this useful accommodation of language, the character of indefeasibility attributed to justice is kept up, and we are saved from the necessity of maintaining that there can be laudable injustice.

The considerations which have now been adduced resolve, I conceive, the only real difficulty in the utilitarian theory of morals. It has always been evident that all cases of justice are also cases of expediency: the difference is in the peculiar sentiment which attaches to the former, as contradistinguished from the latter. If this characteristic sentiment has been sufficiently accounted for; if there is no necessity to assume for it any peculiarity of origin; if it is simply the natural feeling of resentment, moralized by being made coextensive with the demands of social good; and if this feeling not only does but ought to exist in all the classes of cases to which the idea of justice corresponds; that idea no longer presents itself as a stumbling-block to the utilitarian ethics.

Justice remains the appropriate name for certain social utilities which are vastly more important, and therefore more absolute and imperative, than any others are as a class (though not more so than others may be in particular cases); and which, therefore, ought to be, as well as naturally are, guarded by a sentiment not only different in degree, but also in kind; distinguished from the milder feeling which attaches to the mere idea of promoting human pleasure or convenience, at once by the more definite nature of its commands, and by the sterner character of its sanctions.

Beacon Lights of Science

LIGHTNING, THUNDER

AND

LIGHTNING CONDUCTORS.

WITH AN APPENDIX ON THE RECENT CONTROVERSY ON LIGHTNING CONDUCTORS

BY

GERALD MOLLOY, D. D., D. Sc.

ILLUSTRATED.

Lightning, Thunder, and Lightning Conductors.

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LIGHTNING CONDUCTORS.

APPENDIX.

RECENT CONTROVERSY ON LIGHTNING CONDUCTORS.

LIST OF ILLUSTRATIONS.

4

Beacon Lights of Science

LECTURE I

LIGHTNING AND THUNDER.

THE electricity produced by an ordinary electric machine exhibits, under certain conditions, phenomena which bear a striking semblance to the phenomena attendant on lightning. In both cases there is a flash of light; in both there is a report, which, in the case of lightning, we call thunder; and, in both cases, intense heat is developed, which is capable of setting fire to combustible bodies. Further, the spark from an electric machine travels through space with extraordinary rapidity, and so does a flash of lightning, the spark follows a zig-zig course, and so does a flash of lightning; the spark moves silently and harmlessly through metal rods and stout wires, while it forces its way, with destructive effect, through bad conductors, and it is so, too, with a flash of lightning. Lastly, the electricity of a machine is capable of giving a severe shock to the human body; and we know that lightning gives a shock so severe as usually to cause immediate death. For these reasons it was long conjectured by scientific men that lightning is, in its nature, identical with electricity; and that it differs from the electricity of our machines only in this, that it exists in a more powerful and destructive form.

Identity of Lightning and Electricity.— But it was reserved for the celebrated Benjamin Franklin to demonstrate the truth of this conjecture by direct experiment. He first conceived the idea of drawing electrcity from a thundercloud in the same way as it is drawn from the conductor of an electric machine. For this purpose he proposed to place a kind of sentry-box on the summit of a lofty tower, and to erect, on the sentry-box a metal rod, projecting twenty or thirty feet upward into the air, pointed at the end, and having no electrical communication with the earth. He predicted that when a thundercloud would pass over the tower, the metal rod would become charged with electricity, and that an observer stationed in the sentry-box, might draw from it, at pleasure, a succession of electric sparks.

With the magnanimity of a really great man, Franklin published this project to the world; being more solicitous to extend the domain of science by new discoveries, than to secure for himself the glory of having made them. The project was set forth in a letter to Mr. Collinson, of London, which bears date July 29, 1750, and which, in the course of a year or two, was translated into the principal languages of Europe. Two years later the experiment suggested by Franklin was made by Monsieur Dalibard, a wealthy man of science, at his villa near Marly-la-Ville, a few miles from Paris. In the middle of an elevated plain Monsieur Dalibard erected an iron rod, forty feet in length, one inch in diameter, and ending above in a sharp steel point. The iron rod rested on an insulating support, and was kept in position by means of silk cords.

In the absence of Monsieur Dalibard, who was called by business to Paris, this apparatus was watched by an old dragoon, named Coiffier; and on the afternoon of the tenth of May, 1752, he drew sparks from the lower end of the rod at the time that a thundercloud was passing over the neighborhood. Conscious of the importance that would be attached to this phenomenon, the old dragoon summoned, in all haste, the prior of Marly to come and witness it. The prior came without delay, and he was followed by some of the principal inhabitants of the village. In the presence of the little group, thus gathered together, the experiment was repeated — electric sparks were again drawn, in rapid succession, from the iron rod; the prediction of Franklin was fulfilled to the letter; and the identity of lightning and electricity was, for the first time, demonstrated to the world.

Franklin's Experiment.— Meanwhile Franklin had been waiting, with impatience, for the completion of the tower of Christchurch in Philadelphia, on which he intended to make the experiment himself. He even collected money, it is said, to hasten on the building. But, notwithstanding his exertions, the progress of the tower was slow; and his active mind, which could ill brook delay, hit upon another expedient, remarkable alike for its simplicity and for its complete success. He constructed a boy's kite, using, however, a silk pockethandkerchief, instead of paper, that it might not be damaged by rain. To the top of the kite he attached a pointed iron wire about a foot long, and he provided a roll of hempen twine, which he knew to be a conductor of electricity, for flying it. This was the apparatus with which he proposed to explore the nature of a thundercloud.

The thundercloud came late in the afternoon of the fourth of July, 1752, and Franklin sallied out with his kite, accompanied by his son, and taking with him a common door-key and Leyden jar. The kite was soon high in air, and the philosopher awaited the result of his experiment, standing, with his son, under the lee of a cowshed, partly to protect himself from the rain that was coming, and partly, it is said, to shield himself from the ridicule of the passers-by, who, having no sympathy with his philosophical speculations, might be inclined to regard him as a lunatic. To guard against the danger of receiving a flash of lightning through his body, he held the kite by means of a silk ribbon, which was tied to the door-key, the door-key being itself attached to the lower end of the hempen string.

A flash of lightning soon came from the cloud, and a second, and a third; but no sign of electricity could be observed in the kite, or the hempen cord, or the key. Franklin was almost beginning to despair of success, when suddenly he noticed that the little fibres of the cord began to bristle up, just as they would if it were placed near an electric machine in action. He presented the door-key to the knob of the Leyden jar, and a spark passed between them. Presently a shower began to fall; the cord, wetted by the rain, became a better conductor than it had been before, and sparks came more freely. With these sparks he now charged the Leyden jar, and found, to his intense delight, that he could exhibit all the phenomena of electricity by means of the lightning he had drawn from the clouds.

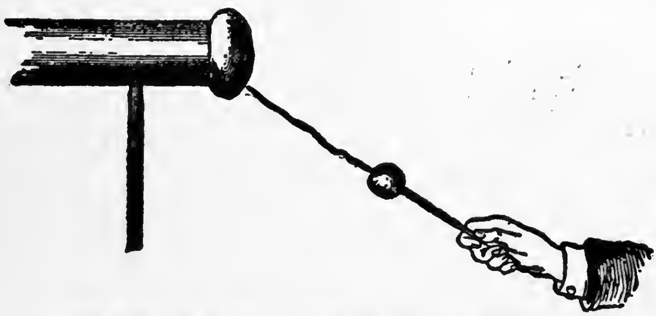
In the following year a similar experiment, with even more striking results, was carried out, in France, by de Romas. Though it is said he had no knowledge of what Franklin had done in America, he, too, used a kite; and, with a view of making the string a better conductor, he interlaced with a thin copper wire. Then, flying his kite in the ordinary way, when it had risen to a height of about 550 feet, he drew sparks from it which, we are told, were upwards of nine feet long, and emitted a sound like the report of a pistol.

Fatal Experiment of Richman.— There can be no doubt that experiments of this kind, made with the electricity of a thunder-cloud, were extremely dangerous; and this was soon proved by a fatal accident. Professor Richman, of St. Petersburg, had erected on the roof of his house a pointed iron rod, the lower end of which passed into a glass vessel, intended, as we are informed, to measure the strength of the charge which he expected to receive from the clouds. On the sixth of August, 1753, observing the approach of a thunderstorm, he hastened to his apparatus; and as he stood near it, with his head bent down, to watch the effect, a flash of lightning passed through his body and killed him on the spot. This catastrophe served to fix public attention on the danger of such experiments, and gave occasion to the saying of Voltaire: "There are some great lords whom we should always approach with extreme precaution, and lightning is one of them."[1] From this time the practice of making experiments directly with the lightning of the clouds seems to have been, by common consent, abandoned.

Immediate Cause of Lightning.— And now, having set before you some of the most memorable experiments by which the identity of lightning and electricity has been demonstrated, I will try to give

[1] "Il y a des grands seigneurs dont il ne faut approcher qu'avec d'extrêmes précautions. Le tonnerre est de ce nombre."— Dict. Philos. art. Foudre.

you a clear conception regarding the immediate cause of lightning, so far as the subject is understood at the present day by scientific men. You know that there are two kinds of electricity, which are called *positive* and *negative;* and that each of them repels electricity of the same kind as itself, while it attracts electricity of the opposite kind. Now, every thundercloud is charged with electricity of one kind or the other, positive or negative; and, as it hovers over the earth, it develops, by what is called *induction,* or influence, electricity of the opposite kind in that part of the earth which is immediately under it. Thus we have two bodies—the cloud and the earth — charged with opposite kinds of electricity, and separated by a stratum of the atmosphere. The two opposite electricities powerfully attract each other; but for a time they are prevented from rushing together by the intervening stratum of air, which is a non-conductor of electricity, and acts as a barrier between them. As the electricity, however, continues to accumulate, the attraction becomes stronger and stronger, until at length it is able to overcome the resistance of this barrier; a violent disruptive discharge



THE ELECTRIC SPARK; A TYPE OF A FLASH OF LGHTNING.

then takes place between the cloud and the earth, and the flash of lightning is the consequence of the discharge.

The whole phenomenon may be illustrated, on a small scale, by means of this electric machine of Carré's which you see before you. When my assistant turns the handle of the machine negative electricity is developed in that large brass cylinder, which in our experiment will represent the thundercloud. At a distance of five or six inches from the cylinder I hold a brass ball, which is in electrical communication with the earth through my body. The electrified brass cylinder acts by induction, or influence on the brass ball, and develops in it, as well as in my body, a charge of positive electricity. Now, the positive electricity of the ball and the negative electricity of the cylinder are mutually attracting each other, but the intervening stratum of air offers a resistance which prevents a discharge from taking place. My assistant, however, continues to work the machine; the two opposite electricities rapidly accumulate on the cylinder and the ball; at length their mutual attraction is strong enough to overcome the resistance interposed between them; a disruptive discharge follows, and at the same moment a spark is seen to pass, accompanied by a sharp snapping report.

This spark is a miniature flash of lightning; and the snapping report is a diminutive peal of thunder. Furthermore, at the moment the spark passes you may observe a slight convulsive movement in my hand and wrist. This convulsive movement represents, on a small scale, the violent shock, generally fatal to life, which is produced by a flash of lightning when it passes through the body.

I can continue to take sparks from the conductor as long as the machine is worked; and it is interesting to observe that these sparks follow an irregular zig-zag course, just as lightning does. The reason is the same in both cases; a discharge betwen two electrified bodies takes place along the line of least resistance; and, owing to the varying condition of the atmosphere, as well as of the minute particles of matter floating in it, the line of least resistance is almost always a zig-zag line.

What a Flash of Lightning is.—Lightning, then, may be conceived as an electrical discharge, sudden and violent in its character, which takes place, through the atmosphere, between two bodies highly charged with opposite kinds of electricity. Sometimes this electrical discharge passes, as I have said, between a cloud and the earth; sometimes it passes between one cloud and and another; sometimes, on a smaller scale, it takes place between the great mass of a cloud and its outlying fragments.

But, if you ask me in what the discharge itself consists, I am utterly unable to tell you. It is usual to speak and write on this subject as if electricity were a material substance, a very subtle fluid, and as if, at the moment the discharge takes place, this fluid passes like a rapid stream, from the body that is positively electrified to the body that is negatively electrified. But we must remember that this is only a conventional mode of expression, intended chiefly to assist our conceptions, and to help us to talk about the phenomena. It does not even profess to represent the objective truth. All that we know for certain is this: that immediately before the discharge the two bodies are highly electrified with opposite kinds of electricity; and, that immediately after the discharge, they are found to have returned to their ordinary condition, or, at least, to have become less highly electrified than they were before.

The flash of light that accompanies an electric discharge is often supposed to be the electricity itself, passing from one body to the other. But it is not; it is simply an effect produced by the discharge. Heat is generated by the expenditure of electrical energy, in overcoming the resistance offered by the atmosphere; and this heat is so intense, that it produces a brilliant incandescence along the path of the discharge. When a spark appears, for example, between the conductor of the machine and this brass ball, it can be shown, by very satisfactory evidence, that minute particles of these solid bodies are first converted into vapor, and then made to glow with intense heat. The gases, too, of which the air is composed, and the solid particles floating in the air, are likewise raised to incandescence. So, too, with lightning; the flash of light is due to the intense heat generated by the electrical discharge, and owes its character to the composition and the density of the atmosphere through which the discharge passes.

Duration of a Flash of Lightning.— How long does a flash of lightning last? You are aware, I dare say, that when an impression of light is made on the eye, the impression remains for a sensible interval of time, not less than the tenth of a second, after the source of light has been extinguished or removed. Hence we continue, in fact, to see the light, for at least the tenth of a second, after the light has ceased. Now, if you reflect how brief is the moment for which a flash of lightning is visible, and if you deduct the tenth of a second from that brief moment, you will see, at once, that the period of its actual duration must be very short indeed.

The exact duration of a flash of lightning is a question on which no settled opinion has yet been accepted generally by scientific men. Indeed, the most widely different statements have been made on the subject, quite recently, by the highest authorities, each speaking apparently with unhesitating confidence. Thus, for example, Professor Mascart describes an experiment, which he says was made by Wheatstone, and which showed that a flash of lightning lasts for less than *one*-thousandth of a second;[1] Professor Everett describes the same experiment, without saying by whom it was made, and gives, as the result, that "the duration of the illumination produced by lightning is certainly less than the *ten*-thousandth of a second;"[2] Professor Tyndall, in his own picturesque way, tells us that "a flash of lightning cleaves a cloud, appearing and disappearing in less than the *hundred*-thousandth of a second;"[3] and according to Professor Tait, of Edinburgh, "Wheatstone has shown lightning certainly lasts less than the *millionth* of a second."[4]

Experiments of Professor Rood.—I cannot say which of these statements is best supported by actual observation; for none of the writers I have quoted gives any reference to the original memoir from which his statement is derived. As far as my own reading goes, I have only come across one original record of experiments, made directly on the flash of lightning itself, with a view to determine the period of its duration. These experiments

[1] Electricité Statique, ii., 561.
[2] Deschanel's Natural Philosophy, Sixth Edition, p. 641.
[3] Fragments of Science, Fifth Edition, p. 311.
[4] Lecture on Thunderstorms, Nature, vol. xxii., p. 341.

were carried out by Professor Ogden Rood, of Columbia College, New York, between the years 1870 and 1873, and are recorded in the *American Journal of Science and Arts.*[1]

For the description of his apparatus, and for the details of his observations, I must refer you to the memoir itself; but I may tell you briefly that the results at which he arrived, if they be accepted, must lead to a considerable modification of the views previously entertained on the subject. In the first place, he satisfied himself that what appears to the eye a single flash of lightning is usually, if not always, multiple in its character; consisting, in fact, of a succession of distinct flashes, which follow one another with such rapidity as to make a continuous impression on the retina. Next, he proceeded to measure approximately the duration of these several component flashes; and he found that it varied over a wide range, amounting sometimes to fully the twentieth of a second, and being sometimes less than the sixteen-hundredth of a second.

Wheatstone's Experiments.— These results are extremely interesting; but we can hardly regard them as finally established, until they have been confirmed by other observers. I may remark, however, that they fit in very well with the experiments made by Professor Wheatstone, many years ago, on the duration of the electric spark, as I told you, is a minature flash of lightning. In these classical experiments, which leave nothing to be desired in point of accuracy, Professor Wheatstone showed that a spark taken directly from a Leyden jar, or a spark taken from the conductor of a powerful electric machine, that is, just such a spark as you have seen here to day, lasts for less than the millionth of a second.

But he also showed that the duration of the spark is greatly increased, when a resisting wire is introduced into the path of the discharge. Thus, for example, when the discharge from a Leyden jar was made to pass through half a mile of copper wire, with breaks at intervals, the spark that appeared at these breaks were found to last for $\frac{1}{24000}$ of a second.[2] Hence we should naturally expect that the period of illumination would be still further increased, in the case of a flash of lightning, where the resistance interposed is enormously greater than in either of the experiments made by Wheatstone.[3]

Experiment of the Rotating Disk.— It would be tedious on an occasion like the present, to enter into an account of Wheatstone's beautiful and ingenious method of investigation, by which the above facts have been established; but I will show you a much more simple experiment which brings home very forcibly to the mind how

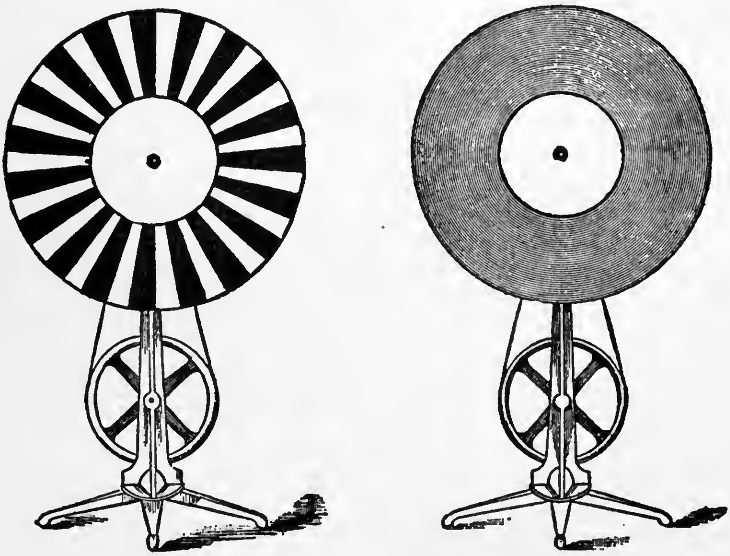
[1] Third Series, vol. v., p. 161.

[2] Phil. Trans. Royal Society, 1834, vol. cxxv., pp. 583–591.

[3] In experiments with a Leyden jar, Feddersen has shown that the duration of the discharge is increased, not only by increasing the striking distance, but also by increasing the size of the jar. Now, a flash of lightning may be regarded as the discharge of a Leyden jar of immense size, with an enormous striking distance; and therefore we should expect that the duration of the discharge should be greatly prolonged. See *American Journal of Science and Arts,* Third Series, vol. i., p. 15.

exceedingly short must be the duration of the electric spark. Here is a circular disk of cardboard, the outer part of which, as you see, is divided into sectors, black and white alternately, while the space about the centre is entirely white. The disk is mounted on a stand, by means of which I can make it rotate with great velocity. When it is put in rotation, the effect on the eye is very striking—the central space remains white as before, but in the outer rim the distinction of black and white absolutely disappear and gives place to a uniform gray. This color is due to the blending together of black and white in equal proportions; the blending being effected, not on the cardboard disk, but on the retina of the eye.

I mentioned just now that an impression made on the retina lasts for the tenth of a second after the cause of it has been removed.



CARDBOARD DISK AS SEEN WHEN AT REST. SAME DISK AS SEEN WHEN IN RAPID ROTATION

Now, when this disk is in rotation, the sectors follow one another so rapidly that the particular part of space occupied at any moment by a white sector will be occupied by a black sector within a time much less than the tenth of a second. It follows that the impression made by each white sector remains on the retina until the following black sector comes into the same position; and, in like manner, the impression made by each black sector remains until the following white sector takes up the position of the black. Therefore, the impression made by the whole outer rim is the impression of black and white combined—that is, the impression of gray.

So far, I dare say, the phenomenon is already familiar to you all. But I propose now to show you the revolving disk illuminated by the electric spark; and you will observe that, at the moment of illumination, the black and white sectors come out as clearly and distinctly as if the disk were standing still.

For the success of this experiment it is desirable, not only to have a brilliant spark in order to secure a good illumination of the disk, but also to have a succession of such sparks, that you may see the phenomenon frequently repeated, and thus be able to observe it at your leisure. To attain these two objects, I have made the arrangement which is before you.

In front of the disk is a large and very powerful Leyden jar. The rod connected with the inner coating rises well above the mouth of the jar, and ends in a brass ball nearly opposite the centre of the disk. Connected with the outer coating of the jar is another rod which likewise ends in a brass ball, and which is so adjusted that the distance between the two balls is about an inch. The two rods are connected respectively with the two conductors of a Holtz machine, so that when the machine is worked the jar is first quickly charged, and then it discharges itself, with a brilliant spark, between the two brass balls. Thus, by continuing to work the machine, we can get, as long as we choose, a succession of sparks following one another at short and regular intervals right in front of the disk.

Everything being now ready, and the room partially darkened, the disk is put in rapid rotation; and you can see, by the twilight that remains, the outer rim a uniform gray, and the central space white. But when my assistant begins to turn the Holtz machine, and brilliant sparks leap out at intervals, the revolving disk, illuminated for a moment at each discharge, seems to be standing still, and shows the black and white sectors distinctly visible.

The reason of this is clear: So brief is the moment for which the spark endures, that the disk, though in rapid motion, makes no sensible advance during that small fraction of time; therefore, in the image on the retina, the impression made by the white sectors remains distinct from the impression made by the black, and the eye sees the disk as it really is.

I may notice, in passing, a very interesting consideration, suggested by this experiment. A cannon ball is now commonly discharged with a velocity of about 1,600 feet a second. Moving with this velocity it is, as you know, under ordinary circumstances, altogether invisible to the eye. But suppose it were illuminated, in the darkness of night, by this electric spark, which lasts, we will say, for the millionth of a second. During the moment of illumination, the cannon ball moves through the millionth part of 1,600 feet, which is a little lesss than the fiftieth of an inch. Practically, we may say that the cannon ball does not sensibly change its place while the spark lasts. Further, the impression it makes on the eye, from the position it occupies at the moment of illumination, remains on the retina for at least the tenth of a second. Therefore, if we are looking toward that particular part of space where the cannon ball happens to be at the moment the spark passes, we must see the cannon ball hanging motionless in the air, though we know it is traveling at the rate of 1,600 feet a second, or about 1,000 miles an hour.

Brightness of a Flash of Lightning.— I should like to say one word about the brightness of a flash of lightning. Somewhat more than thirty years ago, Professor Swan, of Edinburgh, showed that the eye requires a sensible time—about the tenth of a second—to perceive the full brightness of a luminous object. Furthei, he proved, by a series of interesting experiments, that when a flash of light lasts for less than the tenth of a second, its apparent brilliancy to the eye is proportional to the time of its duration.[1] Now consider the consequence of these facts in reference to the brightness of our electric spark. If the spark lasted for the tenth of a second, we should perceive its full brightness; if it lasted for the tenth part of that time, we should see only the tenth part of its brightness; if it lasted for the hundredth part, we should see only the hundredth part of its brightness; and so on. But we know, in point of fact, that it lasts for less than the millionth of a second, that is, less than the hundred-thousandth part of the tenth of a second. Therefore we see only the hundred-thousandth part of its real brightness.

Here is a startling conclusion, and one, I may say, fully justified by scientific evidence. That electric spark, brilliant as it appears to us, is really a hundred thousand times as bright as it seems to be. We cannot speak with the same precision of a flash of lightning; because its duration has not yet been so exactly determined. But if we suppose that a flash of lightning, in a particular case, lasts for the thousandth of a second, it would follow, from the above experiments, that the flash is a hundred times as bright, in fact, as it appears to the eye.

Various Forms of Lightning.— The lightning of which I have spoken hitherto is commonly called *forked* lightning; a name which seems to have been derived from the zig-zag line of light it presents to the eye. But there are other forms under which the electricity of the clouds often makes itself manifest; and to these I would now invite your attention for a few moments. The most common of them all, at least in this country, is that which is familiarly known by the name of *sheet* lightning. This is, probably, nothing else than the lighting up of the atmosphere, or of the clouds, by forked lightning, which is not itself directly visible.

Generally speaking, after a flash of sheet lightning, we hear the rolling of distant thunder. But it sometimes happens, especially in

[1] See original paper by Swan, Trans. Royal Society, Edinburgh, 1849, vol. xvi., pp. 581–603; also, a second paper, *ib.* 1861, vol. xxii., pp. 33–39.

summer time, that the atmosphere is again and again lit up by a sudden glow of light, and yet no thunder is heard. This phenomenon is commonly called *summer* lightning, or *heat* lightning. It is probably due, in many cases, to electrical discharges in the higher regions of the atmosphere, where the air is greatly rarified; and, in these cases, it would seem to resemble the discharges obtained by means of an induction coil in glass tubes containing rarified gases. But there is little doubt that in many cases, too, summer lightning, like ordinary sheet lightning, is due to forked lightning, which is so remote that we can neither see the flash itself directly, nor hear the rolling of the thunder.

Perhaps the most distinct and satisfactory evidence on this subject, derived from actual observation, is contained in the following letter of Professor Tyndall, written in May, 1883: "Looking to the south and south-east from the Bel Alp, the play of silent lightning among the clouds and mountains is sometimes very wonderful. It may be seen palpitating for hours, with a barely appreciable interval between the thrills. Most of those who see it regard it as lightning without thunder—Blitz ohne Donner, Wetterleuchten, I have heard it named by German visitors. The Monte Generoso, overlooking the Lake of Lugano, is about fifty miles from the Bel Alp, as the crow flies. The two points are connected by telegraph; and frequently when the Wetterleuchten, as seen from the Bel Alp, was in full play, I have telegraphed to the proprietor of the Monte Generoso Hotel and learned, in every instance, that our silent lightning so-existed in time with a thunderstorm more or less terriffic in upper Italy.[1]

Another form of lightning, described by many writers, is called *globe* lightning. It is said to appear as a ball of fire, about the size of a child's head, or even larger, which moves for a time slowly about, and then, after the lapse of several seconds, explodes with a terriffic noise, sending forth flashes of fire in all directions, which burn whatever they strike. Many accounts are on record of such phenomena; but they are derived, for most part, from the evidence of persons who were not specially competent to observe, and to describe with precision, the facts that fell under their observation. Hence these accounts, while they are accepted by some, are rejected by others; and it seems to me, in the present state of the question, that the existence of globe lightning can hardly be regarded as a demonstrated fact. At all events, if phenomena of this kind have really occurred, I can only say that nothing we know about electricity, at present, will enable us to account for them.[2]

St. Elmo's Fire.—A much more authentic and, at the same time,

[1] Nature, vol. xxviii., p. 54.

[2] See, however, an attempt to account for this phenomenon in De Larive's Treatise on Electricity, London, 1853–8, vol. iii., pp. 199, 200; and another, quite recently, by Mr. Spottiswoode, in a Lecture on the Electrical Discharge, delivered before the British Association at York, in September, 1881, and published by Longmans, London, p. 42. See also, for recent evidence regarding the phenomenon itself, Scott's Elementary Meteorology, pp. 175–8.

very interesting form, under which the electricity of the clouds sometimes manifests its presence, is known by the name of St. Elmo's fire. This phenomenon at one time presents the appearance of a star, shining at the points of the lances or bayonets of a company of soldiers; at another, it takes the form of a tuft of bluish light, which seems to stream away from the masts and spars of a ship at sea, or from the pointed spire of a church. It was well known to the ancients. Cæsar, in his Commentaries, tells us that, after a stormy night, the iron points of the javelins of the fifth legion seemed to be on fire; and Pliny says that he saw lights, like stars, shining on the lances of the soldiers, keeping watch by night upon the ramparts. When two such lights appeared at once, on the masts of a ship, they were called Castor and Pollux, and were regarded by sailors as a sign of a prosperous voyage. When only one appeared, it was called Helen, and was taken as an unfavorable omen.

In modern times St. Elmo's fire has been witnessed by a host of observers, and all its various phases have been repeatedly described. In the memoirs of Forbin we read that, when he was sailing once in 1696, among the Balearic Islands, a sudden storm came on during the night, accompanied by lightning and thunder. "We saw on the vessel," he says, "more than thirty St. Elmo's fires. Among the rest there was one on the vane of the mainmast more than a foot and a half high. I sent a man up to fetch it down. When he was aloft he cried out that it made a noise like wetted gunpowder set on fire. I told him to take off the vane and come down; but, scarcely had he removed it from its place, when the fire left it and reappeared at the end of the mast, so that it was impossible to take it away. It remained for a long time, and gradually went out."

On the 14th of January, 1824, Monsieur Maxadorf happened to look at a load of straw in the middle of a field just under a dense black cloud. The straw seemed literally on fire — a streak of light went forth from every blade; even the driver's whip shone with a pale-blue flame. As the black cloud passed away, the light gradually disappeared, after having lasted about ten minutes. Again, it is related that on the 8th of May, 1831, in Algiers, as the French artillery officers were walking out after sunset without their caps, each one saw a tuft of blue light on his neighbor's head; and, when they stretched out their hands, a tuft of light was seen at the end of every finger. Not infrequently a traveler in the Alps sees the same luminous tuft on the point of his alpenstock. And quite recently, during a thunder storm, a whole forest was observed to become dark again at the moment of the discharge.[1]

[1] See Jamin, "Cours de Physique," i., 480–1; Tomlinson, "The Thunderstorm," Third Edition, pp. 95–103; "Thunderstorms," a Lecture by Professor Tait, Nature, vol. xxii., p. 356.

The phenomenon may be easily explained. It consists in a gradual and comparatively silent electrical discharge between the earth and the cloud; and generally, but not always, it has the effect of preventing such an accumulation of electricity as would be necessary to produce a flash of lightning. I can illustrate this kind of discharge with the aid of our machine. If I hold a pointed metal rod toward the large conductor, you can see, when the machine is worked and the room darkened, how the point of the rod becomes luminous and shines like a faint blue star. I substitute for the pointed rod the blunt handles of a pair of pliers, and a tuft of blue light is at once developed at the end of each handle, and seems to stream away with a hissing noise. I now put aside the pliers, and open out my hand under the conductor — and observe how I can set up, at pleasure, a luminous tuft at the tips of my fingers. Now and then a spark passes, giving me a smart shock, and showing how the electricity may sometimes accumulate so fast that it cannot be sufficiently dis-

THE BRUSH DISCHARGE, ILLUSTRATING ST. ELMO'S FIRE.

charged by the luminous tuft. Lastly, I present a small bushy branch of a tree to the conductor, and all its leaves and twigs are aglow with bluish light, which ceases for a moment when a spark escapes, to be again renewed when electricity is again developed by the working of the machine.

Now, if you put a thundercloud in the place of that conductor, you can easily realize how, through its influence, the lance and bayonet of the soldier, the alpenstock of the traveler, the pointed spire of a church, the masts of a ship at sea, the trees of a forest, can all be made to glow with a silent electrical discharge which may or may not, according to circumstances, culminate at intervals in a genuine flash of lighting.

Origin of Lightning.— When we seek to account for the origin of lightning, we are confronted at once with two questions of great interest and importance — first, What are the sources from which the electricity of the thundercloud is derived; and, secondly, How does this electricity come to be developed in a form which so far transcends in power the electricity of our machines? These questions have long engaged the attention of scientific men, but I cannot say that they have yet received a perfectly satisfactory solution. Nevertheless, some facts of great scientific value have been established, and some speculations have been put forward, which are well deserving of consideration.

In the first place, it is quite certain that the atmosphere which surrounds our globe is almost always in a state of electrification. Further, the electrical condition of the atmosphere would seem to be as variable as the wind. It changes with the change of season; it changes from day to day; it changes from hour to hour. The charge of electricity is sometimes positive, sometimes negative; sometimes it is strong, sometimes feeble; and the transition from one condition to another is sometimes slow and gradual, sometimes sudden and violent.

As a general rule, in fine, clear weather, the electricity of the atmosphere is positive, and not very strongly developed. In wet weather the charge may be either positive or negative, and is generally strong, especially when there are sudden heavy showers. In fog it is also strong, and almost always positive. In a snowstorm it is very strong, and most frequently positive. Finally, in a thunderstorm it is extremely strong, and generally negative; but it is subject to a sudden change of sign, when a flash of lightning passes or when rain begins to fall.

So far I have simply stated facts, which have been ascertained by careful observations, made at different stations by competent observers, and extending over a period of many years. But as regards the process by which the electricity of the atmosphere is developed, we have, up to the present time, no certain knowledge. It has been said that electricity may be generated in the atmosphere by the friction of the air itself, and of the minute particles floating in it, against the surface of the earth, against trees and buildings, against rocks, cliffs, and mountains. But this opinion, however probable it may be, has not yet been confirmed by any direct experimental investigation.

The second theory is that the electricity of the atmosphere is due, in great part at least, to the evaporation of salt water. Many years ago Pouillet, a French philosopher, made a series of experiments in the laboratory, which seemed to show that evaporation is generally attended with the development of electricity; and, in particular, he satisfied himself that the vapor which passes off from the surface of salt water is always positively electrified. Now, the atmosphere is everywhere charged, more or less, with vapor which comes, almost entirely, from the salt water of the ocean. Hence Pouillet inferred that the chief source of atmospheric electricity is the evaporation of sea water. This explanation would certainly go far to account for the presence of electricity in the atmosphere, if the fact on which it rests were established beyond dispute. But there is some reason to doubt whether the development of electricity, in the experiments of Pouillet, was due simply to the process of evaporation, and not rather to other causes, the influence of which he did not sufficiently take into account.

A conjecture has recently been started that electricity may be generated by the mere impact of minute particles of water vapor against minute particles of air.[1] If this conjecture could be established as a fact, it would be amply sufficient to account for all the electricity of the atmosphere. From the very nature of a gas, the molecules of which it is composed are forever flying about with incredible velocity; and therefore the particles of water vapor and the particles of air, which exist together in the atmosphere, must be incessantly coming into collision. Hence, however small may be the charge of electricity developed at each individual impact, the total amount generated over any considerable area, in a single day, must be very great indeed. It is evident, however, that this method of explaining the origin of atmospheric electricity can only be regarded as, at best, a probable hypothesis, until the assumption on which it rests is supported by the evidence of observation or experiment.

Length of a Flash of Lightning.—It would seem, then, that we are not yet in a position to indicate with certainty the sources from which the electricity of the atmosphere is derived. But whatever these sources may be, there can be little doubt that the electricity of the atmosphere is intimately associated with the minute particles of water vapor of which the thundercloud is eventually built up. This consideration is of great importance when we come to consider the special properties of lightning, as compared with other forms of electricity. The most striking characteristic of lightning is the wonderful power it possesses of forcing its way through the resisting medium of the air. In this respect it incomparably surpasses all forms of electricity that have hitherto been produced by artificial means. The spark of an ordinary electric machine can leap across a space of three or four inches; the machine we have employed in our experiments to-day can give, under favorable circumstances, a spark of nine or ten inches; the longest electric spark ever yet produced artificially is probably the spark of Mr. Spottiswoode's gigantic induction coil; and it does not exceed three feet six inches. But the length of a flash of lightning is not to be measured in inches, or in feet or in yards; it varies from one to two miles, for ordinary flashes, to eight or ten miles in exceptional cases.

This power of discharging itself violently through a resisting medium, in which the thundercloud so far transcends the conductor of an electric machine, is due to the property commonly known among

[1] Professor Tait, On Thunderstorms, Nature, vol. xxii., pp. 436–7.

scientific men as electrical *potential*. The greater the distance to which an electrified body can shoot its flashes through the air, the higher must be its potential. Hence the potential of a thundercloud must be exceedingly high, since its flashes can pierce the air to a distance of several miles. And what I want to point out is, that we are able to account for this exceedingly high potential, if we may only assume that the minute particles of water vapor in the atmosphere have, from any cause, received ever so small a charge of electricity. The number of such particles that go to make up an ordinary drop of rain are to be counted by millions of millions; and it is capable of scientific proof that, as each new particle is added, in the building up of the drop, a rise of potential is necessarily produced. It is clear, therefore, that there is practically no limit to the potential that may be developed by the simple agglomeration of very small cloud particles, each carrying a very small charge of electricity.[1]

This explanation, which traces the exceedingly high potential of lightning to the building up of rain drops in the thundercloud, suggests a reason why it so often happens that immediately after a flash of lightning " the big rain comes dancing to the earth." The potential has been steadily rising as the drops have been getting larger and larger, until at length the potential has become so high that the thundercloud is able to discharge itself, and almost at the same moment the drops have become so large that they can no longer be held aloft against the attracting force of gravity.

Physical Cause of Thunder.— Let us now proceed to consider the phenomenon of thunder, which is so intimately associated with lightning, and which, though perfectly harmless in itself, and though never heard until the real danger is past, often excites more terror in the mind than the lightning flash itself. The sound of thunder, like that of the electric spark, is due to a disturbance caused in the air by the electric discharge. The air is first expanded by the intense heat that is developed along the line of discharge, and then it rushes back again to fill up the partial vacuum which its expansion has produced. This sudden movement gives rise to a series of sound waves, which reach the ear in the form of thunder. But there are certain peculiar characteristics of thunder which are deserving of special consideration.

Rolling of Thunder.— They may be classified, I think, under two heads. First, the sound of thunder is not an instantaneous report like the sound of the electric spark — it is a prolonged peal lasting, sometimes, for several seconds. Secondly, each flash of lightning gives rise, not to one peal only, but to a succession of peals following one another at irregular intervals. These two phenomena, taken together, produce that peculiar effect on the ear which is commonly

[1] See note at the end of this Lecture, p. 196.

described as the *rolling* of thunder; and both of them, I think, may be sufficiently accounted for in accordance with the well-established properties of sound.

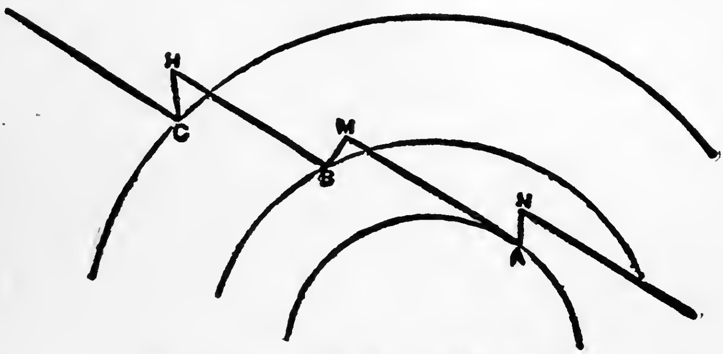
To understand why the sound of thunder reaches the ear as a prolonged peal, we have only to remember that sound takes time to travel. Since a flash of lightning is practically instantaneous, we may assume that the sound is produced at the same moment all along the line of discharge. But the sound waves, setting out at the same moment from all points along the line of discharge, must reach the ear in successive instants of time, arriving first from that point which is nearest to the observer, and last from that point which is most distant. Suppose, for example, that the nearest point of the flash is a mile distant from the observer, and the farthest point two miles—the sound will take about five seconds to come from the nearest point, and about ten seconds to come from the farthest point; and moreover, in each successive instant from the time the first sound reaches the ear, sound will continue to arrive from the successive points between. Therefore the thunder, though instantaneous in its origin, will reach the ear as a prolonged peal extending over a period of five seconds.

Succession of Peals.—The succession of peals produced by a single flash of lightning is due to several causes, each one of which may contribute more or less, according to circumstances, toward the general effect. First, if we accept the results arrived at by Professor Ogden Rood, of Columbia College, what appears to the eye as a single flash of lightning, consists, in fact, as a general rule, of a succession of flashes, each one of which must naturally produce its own peal of thunder; and although the several flashes, if they follow one another at intervals of the tenth of a second, will make one continuous impression on the eye, the several peals of thunder, under the same conditions, will impress the ear as so many distinct peals.

The next cause that I would mention is the zigzag path of the lightning discharge. To make clear to you the influence of this circumstance, I must ask your attention for a moment to the diagram on next page. Let the broken line represent the path of a flash of lightning, and let O represent the position of an observer. The sound will reach him first from the point A, which is nearest to him, and then it will continue to arrive in successive instants from the successive points along the line A N and along the line A M, thus producing the effect of a continuous peal. Meanwhile the sound waves have been traveling from the point B, and in due time will reach the observer at O. Coming as they do in a different direction from the former, they will strike the ear as the beginning of a new peal which, in its turn, will be prolonged by the sound waves arriving, in successive instants, from the successive points along the line B M and B H.

A little later, the sound will arrive from the more distant point C, and a third peal will begin. And so there will be several distinct peals proceeding, so to speak, from several distinct points in the path of the lightning flash.

A third cause to which the succession of peals may be referred is to be found in the minor electrical discharges that must often take place within the thundercloud itself. A thundercloud is not a continuous mass like the metal cylinder of this electric machine — it has many outlying fragments, more or less imperfectly connected with the principal body. Moreover, the material of which the cloud is composed is only a very imperfect conductor as compared with our brass cylinder. For these two reasons it must often happen, about the time a flash of lightning passes, that different parts of the cloud will be in such different electrical conditions as to give rise to electrical discharges within the cloud itself. Each of these discharges produces its own peal of thunder; and thus we may have a number



ORIGIN OF SUCCESSIVE PEALS OF THUNDER.

of minor peals, sometimes preceding and sometimes following the great crash which is due to the principal discharge.

Lastly, the influence of echo has often a considerable share in multiplying the number of peals of thunder. The waves of sound, going forth in all directions, are reflected from the surfaces of mountains, forests, clouds, and buildings, and coming back from different quarters, and with varying intensity, reach the ear like the roar of distant artillery. The striking effect of these reverberations in a mountain district has been described by a great poet in words which, I daresay, are familiar to most of you:

"Far along,
From peak to peak, the rattling crags among,
Leaps the live thunder! Not from one lone cloud,
But every mountain now has found a tongue,
And Jura answers from her misty shroud
Back to the joyous Alps, that call to her aloud!"

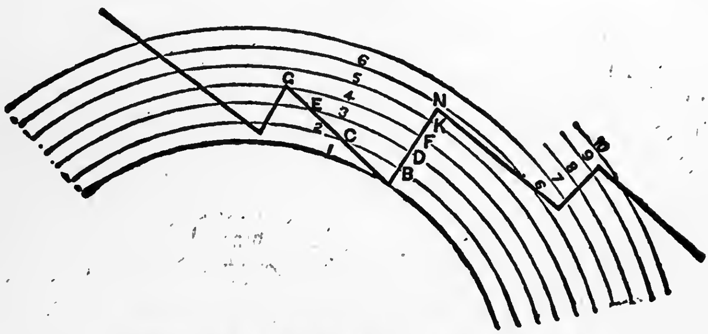
Variations of Intensity in Thunder.—From what has been said, it is easy to understand how the general roar of thunder is subject to great changes of intensity, during the time it lasts, according to the number of peals that may be arriving at the ear of an observer in each particular moment. But every one must have observed that even an individual peal of thunder often undergoes similar changes, swelling out at one moment with great power and the next moment rapidly dying away. To account for this phenomenon, I would observe, first, that there is no reason to suppose that the disturbance caused by lightning is of exactly the same magnitude at every point of its path. On the contrary, it would seem very probable that the amount of this disturbance is, in some way, dependent on the resistance which the discharge encounters. Hence the intensity of the sound waves sent forth by a flash of lightning is probably very different at different parts of its course; and each individual peal will swell out on the ear or die away, according to the greater or less intensity of the sound waves that reach the ear in each successive moment of time.

But there is another influence at work which must produce variations in the loudness of a peal of thunder, even though the sound waves, set in motion by the lightning, were everywhere of equal intensity. This influence depends on the position of the observer in relation to the path of the lightning flash. At one part of its course the lightning may follow a path which remains for a certain length at nearly the same distance from the observer; then all the sound produced along this length will reach the observer nearly at the same moment, and will burst upon the ear with great intensity. At another part, the lightning may for an equal length go right away from the observer; and it is evident that the sound produced along this length will reach the observer in successive instants and consequently produce an effect comparatively feeble.

With a view to investigate this interesting question a little more closely, let me suppose the position of the observer taken as a centre, and a number of concentric circles drawn, cutting the path of the lightning flash, and separated from one another by a distance of 110 feet, measured along the direction of the radius. It is evident that all the sound produced between any two consecutive circles will reach the ear within a period which must be measured by the time that sound takes to travel 110 feet, that is, within the tenth of a second. Hence, in order to determine the quantity of sound that reaches the ear in successive periods of one-tenth of a second, we have only to observe how much is produced between each two consecutive circles. But on the supposition that the sound waves, set in motion by the flash of lightning, are of equal intensity at every point of its path, it is clear that the quantity of sound developed between each two consecutive circles will be simply proportional to the length of the path enclosed between them.

With these principles established, let us now follow the course of a peal of thunder, in the diagram before us. This broken line, drawn almost at random, represents the path of a flash of lightning; the observer is supposed to be placed at O, which is the centre of the concentric circles; these circles are separated from one another by a distance of 110 feet, measured in the direction of the radius; and we want to consider how any one peal of thunder may vary in loudness in the successive periods of one-tenth of a second.

Let us take, for example, the peal which begins when the sound waves reach the ear from the point A. In the first unit of time the sound that reaches the ear is the sound produced along the lines A B and A C; in the second unit, the sound produced along the lines B D and C E; in the third unit, the sound produced along D F and E G. So far the peal has been fairly uniform in its intensity; though there has been a slight falling off in the second and third units of time, as



VARIATIONS OF INTENSITY IN A PEAL OF THUNDER.

compared with the first. But in the fourth unit there is a considerable falling away of the sound; for the line F K is only about one-third as long as D F and E G taken together; therefore the quantity of sound that reaches the ear in the fourth unit of time is only one-third of that which reaches it in each of the three preceding units; and consequently the sound is only one-third as loud. In the fifth unit, however, the peal must rise to a sudden crash; for the portion of the lightning path inclosed between the fifth and sixth circles is about six times as great as that between the fourth and fifth; therefore the intensity of the sound will be suddenly increased about sixfold. After this sudden crash, the sound as suddenly dies away in the sixth unit of time; it continues feeble as the path of the lightning goes nearly straight away from the observer; it swells again slightly in the ninth unit of time; and then continues without much variation to the end. This is only a single illustration, but it seems quite sufficient to show that the changes of intensity in a peal of thunder must be largely due to the position of the spectator in relation to the several parts of the lightning flash.

Distance of a Flash of Lightning.—I need hardly remind you that, by observing the interval that elapses between the flash of lightning and the peal of thunder that follows it, we may estimate approximately the distance of the nearest point of the discharge. Light travels with such amazing velocity that we may assume, without any sensible error, that we see the flash of lightning at the very moment in which the discharge takes place. But sound, as we have seen, takes a sensible time to travel even short distances; and therefore a measurable interval almost always elapses between the moment in which the flash is seen and the moment in which the peal of thunder first reaches the ear. And the distance through which sound travels in this interval will be the distance of the nearest point through which the discharge has passed. Now, the velocity of sound in air varies slightly with the temperature; but, at the ordinary temperature of our climate, we shall not be far astray if we allow 1,100 feet for every second, or about one mile for every five seconds.

You will observe also that, by repeating this observation, we can determine whether the thundercloud is coming toward us, or going away from us. So long as the interval between each successive flash and the corresponding peal of thunder, continues to get shorter and shorter, the thundercloud is approaching; when the interval begins to increase, the thundercloud is receding from us, and the danger is passed.

The crash of thunder is terrific when the lightning is close at hand; but it is a curious fact, that the sound does not seem to travel as far as the report of an ordinary cannon. We have no authentic record of thunder having been heard at a greater distance than from twelve to fiften miles, whereas the report of a single cannon has been heard at five times that distance; and the roar of artillery in battle, at a greater distance still. On the occasion of the Queen's visit to Cherbourg, in August, 1858, the salute fired in honor of her arrival was heard at Bonchurch, in the Isle of Wright, a distance of sixty miles. It was also heard at Lyme Regis, in Dorsetshire, which is eighty-five miles from Cherbourg, as the crow flies; and we are told that, not only was it audible in its general effect, but the report of individual guns was distinctly recognized. The artillery of Waterloo is said to have been heard at the town of Creil, in France, 115 miles from the field of battle; and the cannonading at the siege of Valenciennes, in 1793, was heard, from day to day at Deal, on the coast of England, a distance of 120 miles.[1]

So far, I have endeavored to set forth some general ideas on the nature and origin of lightning, and of the thunder that accompanies

[1] See Tomlinson, The Thunderstorm, pp. 87–9.

it. In my next Lecture I propose to give a short account of the destructive effects of lightning, and to consider how these effects may best be averted by means of lightning conductors.

Note to Page 190.

On the High Potential of a Flash of Lightning.

The potential of an electrified sphere is equal to the quantity of electricity with which the sphere is charged, divided by the radius of the sphere. Now the minute cloud particles, which go to make up a drop of rain, may be taken to be very small spheres; and if v represent the potential of each one, q the quantity of electricity with which it is charged, and r the radius of the sphere, we have $v=\frac{q}{r}$. Suppose 1,000 of these cloud particles to unite into one; the quantity of electricity in the drop, thus formed, will be 1,000 q; and the radius, which increases in the ration of the cube root of the volume, will be 10 r. Therefore the potential of the new sphere will be $\frac{1000q}{10r}$, or $100\frac{q}{r}$; that is to say, it will be 100 times as great as the potential of each of the cloud particles which compose it. When a million of cloud particles are blended into a single drop, the same process will show that the potential has been increased ten thousandfold; and when a drop is produced by the agglomeration of a million of millions of cloud particles, the potential of the drop will be a hundred million times as great as that of the individual particles.[1]

LECTURE II.

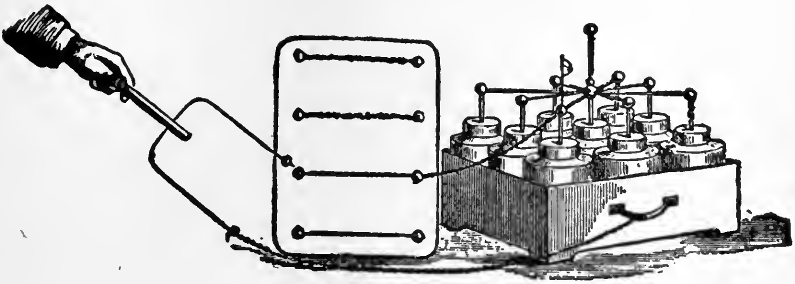
LIGHTNING CONDUCTORS.

THE effects of lightning, on the bodies that it strikes, are analogous to those which may be produced by the discharge of our electric machines and Leyden jar batteries. When the discharge of a battery traverses a metal conductor of sufficient dimensions to allow it an easy passage, it makes its way along silently and harmlessly. But if the conductor be so thin as to offer considerable resistance, then the conductor itself is raised to intense heat, and may be melted, or even converted into vapor, by the discharge.

On opposite page is shown a board on which a number of very thin wires have been stretched, over white paper, between brass balls. The wires are so thin that the full charge of the battery before you, which consists of nine large Leyden jars, is quite sufficient to convert them in an instant into vapor. I have already, on former occasions, sent the charge through two of these wires, and nothing remains of them now but the traces of their vapor, which mark the

[1] See Tait on Thunderstorms, Nature, vol. xxii., p. 436.

path of the electric discharge from ball to ball. At the present moment the battery stands ready charged, and I am going to discharge it through a third wire, by means of this insulated rod which I hold in my hand. The discharge has passed; you saw a flash,



DISCHARGE OF LEYDEN JAR BATTERY THROUGH THIN WIRES.

and a little smoke; and now, if you look at the paper, you will find that the wire is gone, but that it has left behind the track of its incandescent vapor, marking the path of the discharge.

Destruction of Buildings by Lightning.— We learn from this experiment that the electricity stored up in our battery passes, without visible effect, through the stout wire of a discharging rod, but that it instantly converts into vapor the thin wire stretched across the spark board. And so it is with a flash of lightning. It passes harmlessly, as every one knows, through a stout metal rod, but when it comes across bell wires or telegraph wires, it melts them, or converts them into vapor. On the sixteenth of July, 1759, a flash of lightning struck a house in Southwark, on the south side of London, and followed the line of the bell wire. After the lightning had passed, the wire was no longer to be found; but the path of the lightning was clearly marked by patches of vapor which were left, here and there, adhering to the surface of the wall. In the year 1754, the lightning fell on a bell tower at Newbury, in the United States of America, and having dashed the roof to pieces, and scattered the fragments about, it reached the bell. From this point it followed an iron wire, about as thick as a knitting needle, melting it as it passed along, leaving behind a black streak of vapor on the surface of the walls.

Again, the electric discharge, passing through a bad conductor, produces mechanical disturbance, and, if the substance be combustible, often sets it on fire. So, too, as you know, the lightning flash, falling on a church spire, dashes it to pieces, knocking the stones about in all directions, while it sets fire to ships and wooden buildings; and more than once it has caused great devastation by exploding powder magazines.

Let me give you one or two examples: In January, 1762, the lightning fell on a church tower in Cornwall, and a stone—three hundredweight—was torn from its place and hurled to a distance of 180 feet, while a smaller stone was projected as far as 1,200 feet from the building. Again, in 1809, the lightning struck a house not far from Manchester, and literally moved a massive wall twelve feet high and three thick to a distance of several feet. You may form some conception of the enormous force here brought into action, when I tell you that the total weight of mason-work moved on this occasion was not less than twenty-three tons.

The church of St. George, at Leicester, was severely damaged by lightning on the 1st of August, 1846. About 8 o'clock in the evening the rector of the parish saw a vivid streak of light darting with incredible velocity against the upper part of the spire. "For the distance of forty feet on the eastern side, and nearly seventy on the west, the massive stonework of the spire was instantly rent asunder and laid in ruins. Large blocks of stone were hurled in all directions, broken into small fragments, and in some cases, there is reason to believe, reduced to powder. One fragment of considerable size was hurled against the window of a house three hundred feet distant, shattering to pieces the woodwork, and strewing the room within with fine dust and fragments of glass. It has been computed that a hundred tons of stone were, on this occasion, blown to a distance of thirty feet in three seconds. In addition to the shivering of the spire, the pinnacles at the angles of the tower were all more or less damaged, the flying buttresses cracked through and violently shaken, many of the open battlements at the base of the spire knocked away, the roof of the church completely riddled, the roofs of the side entrances destroyed, and the stone staircases of the gallery shattered."[1]

Lightning has been at all times the cause of great damage to property by its power of setting fire to whatever is combustible. Fuller says, in his Church History, that "scarcely a great abbey exists in England which once, at least, has not been burned by lightning from heaven." He mentions, as examples, the Abbey of Croyland twice burned, the Monastery of Canterbury twice, the Abbey of Peterborough twice; also the Abbey of St. Mary's, in Yorkshire, the Abbey of Norwich, and several others. Sir William Snow Harris, writing about twenty years ago, tells us that "the number of churches and church spires wholly or partly destroyed by lightning is beyond all belief, and would be too tedious a detail to enter upon. Within a comparatively few years, in 1822 for instance, we find the magnificent Cathedral of Rouen burned, and, so lately as 1850, the beautiful Cathedral of Saragossa, Spain, struck by lightning during divine service and set on fire. In March of last year a dispatch from our Minister at Brussels, Lord Howard

[1] The Thunderstorm, by Charles Tomlinson, F. R. S., Third Edition, pp. 153–4.

de Walden, dated the 24th of February, was forwarded by Lord Russell to the Royal Society, stating that, on the preceding Sunday, a violent thunderstorm had spread over Belgium; that twelve churches had been struck by lightning; and that three of these fine old buildings had been totally destroyed."[1]

Even in our own day the destruction caused by fires produced through the agency of lightning is very great—far greater than is commonly supposed. No general record of such fires is kept, and consequently our information on the subject is very incomplete and inexact. I may tell you, however, one small fact which, so far as it goes, is precise enough and very significant. In the little province of Schleswig-Holstein, which occupies an area less than one-fourth of the area of Ireland, the Provincial Fire Assurance Association has paid in sixteen years, for damage caused by lightning, somewhat over £100,000, or at the rate of more than £6,000 a year. The total loss of property every year in this province, due to fire caused by lightning, is estimated at not less than £12,500.[2]

Destruction of Ships at Sea.— The destructive effects of lightning on ships at sea, before the general adoption of lightning conductors, seems almost incredible at the present day. From official records it appears that the damage done to the Royal Navy of England alone involved an expenditure of from £6,000 to £10,000 a year. We are told by Sir William Snow Harris, who devoted himself for many years to this subject with extraordinary zeal and complete success, that between the year 1810 and the year 1815—that is, within a period of five years—"no less than forty sail of the line, twenty frigates, and twelve sloops and corvettes were placed *hors de combat* by lightning. In the merchant navy, within a comparatively small number of years, no less than thirty-four ships, most of them large vessels with rich cargoes, have been totally destroyed—been either burned or sunk—to say nothing of a host of vessels partially destroyed or severely damaged."[3]

And these statements, be it observed, take no account of ships that were simply reported as missing, some of which, we can hardly doubt, were struck by lightning in the open sea, and went down with all hands on board. A famous ship of forty-four guns, the *Resistance,* was struck by lightning in the Straits of Malacca, and the powder magazine exploding, she went to the bottom. Of her whole crew only three were saved, who happened to be picked up by a passing boat. It has been well observed that, were it not for these three chance survivors, nothing would have been known concerning the fate of the vessel, and she would have been simply recorded as missing in the Admiralty lists.

[1] Two Lectures on Atmospheric Electricity and Protection from Lightning, published at the end of his Treatise on Frictional Electricity, p. 273.

[2] See Report of Lightning Rod Conference, p. 119. [3] *Loco citato.*

Nothing is more fearful to contemplate than the scene on board a ship when she is struck by lightning in the open sea, with the winds howling around, the waves rolling mountains high, the rain coming down in torrents, and the vivid flashes lighting up the gloom at intervals, and carrying death and destruction in their track. I will read you one or two brief accounts of such a scene, given in the pithy but expressive language of the sailor. In January, 1786, the *Thisbe,* of thirty-six guns, was struck by lightning off the coast of Scilly, and reduced to the condition of a wreck. Here is an extract from the ship's log: "Four A. M., strong gales; handed mainsail and main topsail; hove to with storm staysails; blowing very heavy, S. E. 4.15, a flash of lightning, with tremendous thunder, disabled some of our people. A second flash set the mainsail, main-top, and mizen staysails on fire. Obliged to cut away the mainmast; this carried away mizen top-mast and fore top-sail yard. Found foremast also shivered by the lightning. Fore top-mast went over the side about 9 A. M. Set the foresail."[1]

A few years later, in March, 1796, the *Lowestoffe* was struck in the Mediterranean, and we read as follows in the log of the ship: "North end of Minorca; heavy squalls; hail, rain, thunder, and lightning. 12.15, ship struck by lightning, which knocked three men from the masthead, one killed. 12.30, ship again struck; main top-mast shivered in pieces; many men struck senseless on the decks. Ship again struck, and set on fire in the masts and rigging; mainmast shivered in pieces; fore top-mast shivered; men benumbed on the decks, and knocked out of the top; one man killed on the spot. 1.30, cut away the mainmast; employed clearing wreck. 4, moderate; set the foresail."[2]

Again, in 1810, the *Repulse,* a ship of seventy-four guns, was struck, off the coast of Spain. "The wind had been variable in the morning and at 12.35 there was a heavy squall, with rain, thunder, and lightning. The ship was struck by two vivid flashes of lightning, which shivered the maintop-gallant mast, and severely damaged the mainmast. Seven men were killed on the spot; three others only survived a few days; and ten others were maimed for life. After the second discharge the rain fell in torrents. The ship was more completely crippled than if she had been in action, and the squadron, then engaged on a critical service, lost for a time one of its fastest and best ships."[3]

Destruction of Powder Magazines.— Not less appalling is the devastation caused by lightning when it falls on a powder magazine. Here is a striking example: On the eighteenth of August, 1769, the tower of St. Nazaire, at Brescia, was struck by lightning. Underneath the tower about 200,000 pounds of gunpowder, belong-

[1] Sir William Snow Harris, *loco citato*, p. 274.
[2] *Id.*, p. 275.
[3] The Thunderstorm, by Charles Tomlinson, F. R. S., Third Edition, p. 172.

ing to the Republic of Venice, were stored in vaults. The powder exploded, leveling to the ground a great part of the beautiful city of Brescia, and burying thousands of its inhabitants in the ruins. It is said that the tower itself was blown up bodily to a great height in the air, and came down in a shower of stones. This is, perhaps, the most fearful disaster of the kind on record. But we are not without examples in our own times. In the year 1856 the lightning fell on the Church of St. John, in the Island of Rhodes. A large quantity of gunpowder had been deposited in the vaults of the church. This was ignited by the flash; the building was reduced to a mass of ruins, a large portion of the town was destroyed, and a considerable number of the inhabitants were killed. Again, in the following year, the magazine of Joudpore, in the Bombay Presidency, was struck by lightning. Many thousand pounds of gunpowder were blown up, five hundred houses were destroyed, and nearly a thousand people are said to have been killed.[1]

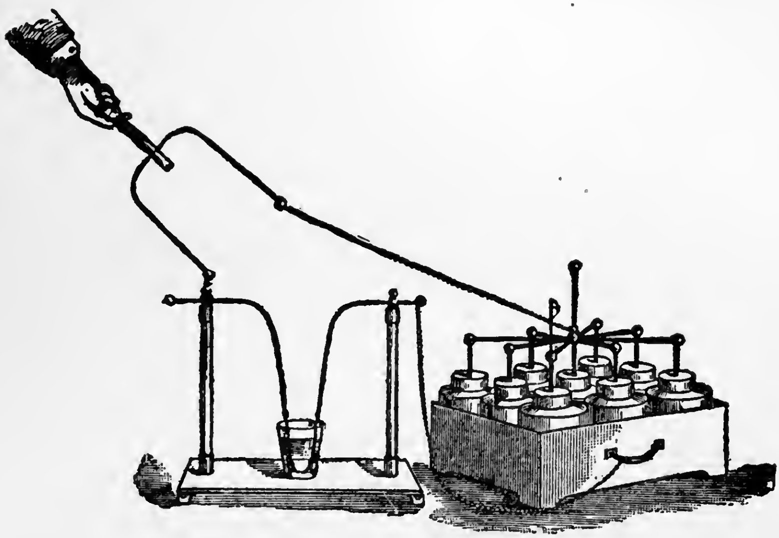
Experimental Illustrations.—And now, before proceeding further, I will make one or two experiments, with a view of showing that the electricity of our machines is capable of producing effects similar to those produced by lightning, though immeasurably inferior in point of magnitude. Here is a common tumbler, about three-quarters full of water. Into it I introduce two bent rods of brass, which are carefully insulated below the surface of the water by a covering of india-rubber. The points, however, are exposed, and come to within an inch of one another, near the bottom of the tumbler. Outside the tumbler, the brass rods are mounted on a stand, by means of which I can send the full charge of this Leyden jar battery through the water, from point to point. Since water is a bad conductor of electricity, as compared with metals, the charge encounters great resistance in passing through it, and in overcoming this resistance produces considerable mechanical commotion, which is usually sufficient to shiver the glass to pieces.

To charge the battery will take about twenty turns of this large Holtz machine. Observe how the pith ball of the electroscope rises as the machine is worked, showing that the charge is going in. And now it remains stationary; which is a sign that the battery is fully charged and can receive no more. You will notice that the outside coating of the battery has been already connected with one of the brass rods dipping into the tumbler of water. By means of this discharger I will now bring the inside coating into connection with the other rod. And see before contact is actually made, the spark has leaped across, and our tumbler is violently burst asunder from top to bottom.

[1] See for these facts, Anderson, Lightning Conductors, p. 197; Tomlinson, The Thunderstorm, pp. 167–9; Harris, *loco citato*, pp. 273–4.

This will probably appear to you a very small affair, when compared with the tearing asunder of solid masonry, and the hurling about of stones by the ton weight. No doubt it is; and that is just one of the lessons we have to learn from the experiment we have made. For, not only does it show us that effects of this kind may be caused by electricity artificially produced, but it brings home forcibly to the mind how incomparably more powerful is the lightning of the clouds than the electricity of our machines.

The property which electricity has of setting fire to combustible substances may be easily illustrated. This india rubber tube is connected with the gas pipe under the floor, and to the end of the tube is fitted a brass stop-cock which I hold in my hand. I open the cock, and allow the jet of gas to flow toward the conductor of

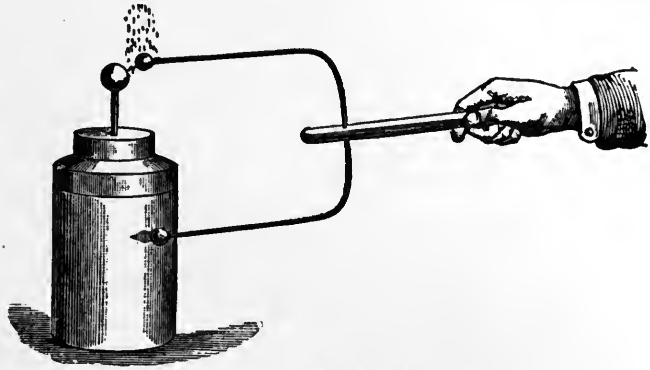


GLASS VESSEL BROKEN BY DISCHARGE OF LEYDEN JAR BATTERY.

Carré's machine, while my assistant turns the handle; a spark passes, and the gas is lit. Again, my assistant stands on this insulating stool, placing his hand on the large conductor of the machine, while I turn the handle. His body becomes electrified, and when he presents his knuckle to this vessel of spirits of wine, which is electrically connected with the earth, a spark leaps across, and the spirits of wine are at once in a blaze. Once more; I tie a little gun-cotton around one knob of the discharging rod, and then use it to discharge a small Leyden jar; at the moment of the discharge the gun-cotton is set on fire.

It would be easy to explode gunpowder with the electric spark, but the smoke of the explosion would make the lecture-hall very unpleasant for the remainder of the lecture. I propose, therefore, to substitute for gunpowder an explosive mixture of oxygen and hydrogen, with which I have filled this little metal flask, commonly known as Volta's pistol. By a very simple contrivance, the electric spark is discharged through the mixture, when I hold the flask toward the conductor of the machine. A cork is fitted tightly into the neck of the flask, and at the moment the spark passes you hear a loud explosion, and you see the cork driven violently up to the ceiling.

Destruction of Life.—The last effect of lightning to which I shall refer, and which, perhaps, more than any other, strikes us with terror, is the sudden and utter extinction of life, when the lightning flash descends on man or on beast. So swift is this effect, in most cases, that death is, in all probability, absolutely painless, and the victim is dead before he can feel that he is struck. I cannot give you, with any degree of exactness, the number of people killed every year by lightning, because the record of such deaths has been hitherto very imperfectly kept, in almost all countries, and is, beyond doubt, very



GUN-COTTON SET ON FIRE BY ELECTRIC SPARK.

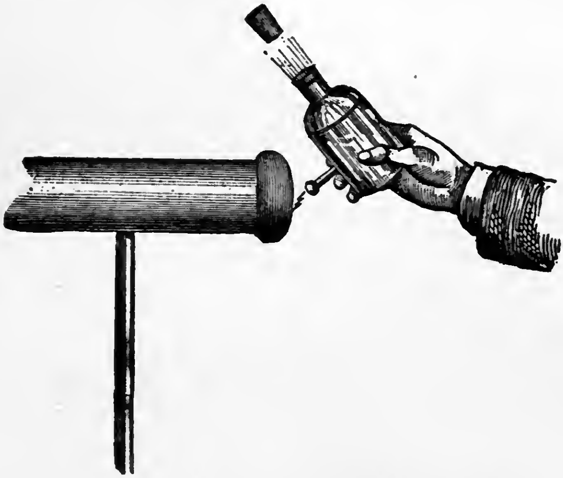
incomplete. But perhaps you will be surprised to learn that the number of deaths by lightning actually recorded is, on an average, in England about 22 every year, in France 80, in Prussia 110, in Austria 212, in European Russia 440.[1]

So far as can be gathered from the existing sources of information, it would seem that the number of persons killed by lightning is, on the whole, about one in three of those who are struck. The rest are sometimes only stunned, sometimes more or less burned, sometimes made deaf for a time, sometimes partially paralyzed. On particular occasions, however, especially when the lightning falls on a large assembly of people, the number of persons struck down and slightly injured, in proportion to the number killed, is very much increased.

An interesting case of this kind is reported by Mr. Tomlinson. "On the twenty-ninth of August, 1847, at the parish church of Welton,

[1] See Anderson, Lightning Conductors, pp. 170–5.

Lincolnshire, while the congregation were engaged in singing the hymn before the sermon, and the Rev. Mr. Williamson had just ascended the pulpit, the lightning was seen to enter the church from the belfry, and instantly an explosion occurred in the centre of the edifice. All that could move made for the door, and Mr. Williamson descended from the pulpit, endeavoring to allay the fears of the people. But attention was now called to the fact that several of the congregation were lying in different parts of the church, apparently dead, some of whom had their clothing on fire. Five women were found injured, and having their faces blackened and burned, and a boy had his clothes almost entirely consumed. A respected old parishioner, Mr. Brownlow, aged sixty-eight, was discovered lying at the bottom of his pew, immediately beneath one of the chandeliers, quite dead. There were no marks on the body, but the buttons of his



VOLTA'S PISTOL; EXPLOSION CAUSED BY ELECTRIC SPARK.

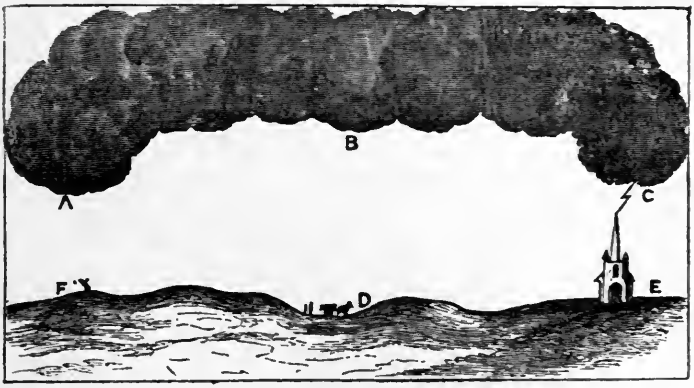
waistcoat were melted, the right leg of his trousers torn down, and his coat literally burnt off. His wife in the same pew received no injury."[1]

Not less striking is the story told by Dr. Plummer, surgeon of the Illinois Volunteers, in the *Medical and Surgical Reporter* of June 19, 1865: "Our regiment was yesterday the scene of one of the most terrible calamities which it has been my lot to witness. About two o'clock a violent thunderstorm visited us. While the old guard was being turned out to receive the new, a blinding flash of lightning was seen, accompanied instantly by a terrific peal of thunder. The whole of the old guard, together with part of the new, were thrown violently to the earth. The shock was so severe and sudden that, in most cases, the rear rank men were thrown across the front rank men. One

[1] The Thunderstorm, pp. 158–9. See also an account of four persons who were struck on the Matterhorn, in July, 1869, all of whom were hurt, and none killed: Whymper's Scrambles Among the Alps, pp. 414, 415.

man was instantly killed, and thirty-two men were more or less severely burned by the electric fluid. In some instances the men's boots and shoes were rent from their feet and torn to pieces, and, strange as it may appear, the men were injured but little in the feet. In all cases the burns appear as if they had been caused by scalding-hot water, in many instances the skin being shriveled and torn off. The men all seem to be doing well, and a part of them will be able to resume their duties in a few days."

The Return Shock.—It sometimes happens that people are struck down and even killed at the moment a discharge of lightning takes place between a cloud and the earth, though they are very far from the point where the flash is actually seen to pass; while others, who are situated between them and the lightning, suffer very little, or perhaps not at all. This curious phenomenon was first carefully investigated by Lord Mahon in the year 1779, and was called by him



THE RETURN SHOCK ILLUSTRATED.

the "return shock." His theory, which is now commonly accepted, may be easily understood with the aid of the sketch before you.

Let us suppose ABC to represent the outline of a thundercloud which dips down toward the earth at A and at C. The electricity of the cloud develops by inductive action a charge of the opposite kind in the earth beneath it. But the inductive action is most powerful at E and F, where the cloud comes nearest to the earth. Hence, bodies situated near these points may be very highly electrified as compared with bodies at a point between them, such as D. Now, when a flash of lightning passes at E, the under part of the cloud is at once relieved of its electricity, its inductive action ceases, and, therefore, a person situated at F suddenly ceases to be electrified. This sudden change from a highly electrified to a neutral state involves a shock to his system which may be severe enough to stun or even to kill him.

Meanwhile, people at D, having been also electrified to some extent by the influence of the thundercloud, must in like manner undergo a change in their electrical condition when the flash of lightning passes, but this change will be less violent because they were less highly electrified.

Many experiments have been devised to illustrate this theory of Lord Mahon. But the best illustration I know is furnished by this electric machine of Carré's. If you stand near one end of the large conductor when the machine is in action and sparks are taken from the other end, you will feel a distinct electric shock every time a spark passes. The large conductor here takes the place of the cloud, the spark that passes at one end represents the flash of lightning, and the observer at the other end gets the return shock, though he is at a considerable distance from the point where the flash is seen.

An experiment of this kind, of course, cannot be made sensible to a large audience like the present. But I can give you a good idea of the effect by means of this tuft of colored papers. While the machine is in action I hold the tuft of papers near that end of the conductor which is farthest from the point where the discharge takes place. You see the paper ribbons are electrified by induction, and, in virtue of mutual repulsion, stand out from one another " like quills upon the fretful porcupine." But, when a spark passes, the inductive action ceases, the paper ribbons cease to be electrified, and the whole tuft suddenly collapses into its normal state.

While fully accepting Lord Mahon's theory of the return shock as perfectly good so far as it goes, I would venture to point out another influence which must often contribute largely to produce the effect in question, and which is not dependent on the form of the cloud. It may easily happen, from the nature of the surface in the district affected by a thundercloud, that the point of most intense electrification—say E in the figure—is in good electrical communication with a distant point, such as F, while it is very imperfectly connected with a much nearer point, D. In such a case it is evident that bodies at F will share largely in the highly-electrified condition of E, and also share largely in the sudden change of that condition the moment the flash of lightning passes ; whereas bodies at D will be less highly electrified before the discharge, and less violently disturbed when the discharge takes place.

This principle may be illustrated by a very simple experiment. Here is a brass chain about twenty feet long. One end of it I hand to any one among the audience who will kindly take hold of it ; the other end I hold in my hand. I now stand near the conductor of the machine ; and will ask some one to stand about ten feet away from me, near the middle of the chain, but without touching it. Now observe what happens when the machine is worked and I take a spark from the conductor: My friend at the far end of the chain, twenty feet away, gets a shock nearly as severe as the one I get myself, because he is in good electrical communication with the point where the discharge takes place. But my more fortunate friend, who is ten feet nearer to the flash, is hardly sensible of any effect, because he is connected with me only through the floor of the hall, which is, comparatively speaking, a bad conductor of electricity.

Summary.—Let me now briefly sum up the chief destructive effects of lightning. First, with regard to good conductors: though it passes harmlessly through them if they be large enough to afford it an easy passage, it melts and converts them into vapor if they be of such small dimensions as to offer considerable resistance. Secondly, lightning acts with great mechanical force on bad conductors; it is capable of tearing asunder large masses of masonry, and of projecting the fragments to a considerable distance. Thirdly, it sets fire to combustible materials. And lastly, it causes the instantaneous death of men and animals.

Franklin's Lightning Rods.—The object of lightning conductors is to protect life and property from these destructive effects. Their use was first suggested by Franklin, in 1749, even before his famous experiment with the kite; and immediately after that experiment, in 1752, he set up, on his own house, in Philadelphia, the first lightning conductor ever made. He even devised an ingenious contrivance, by means of which he received notice when a thundercloud was approaching. The contrivance consisted of a peal of bells, which he hung on his lightning conductor, and which were set ringing whenever the lightning conductor became charged with electricity.

Franklin's lightning rods were soon adopted in America; and he himself contributed very much to their popularity by the simple and lucid instructions he issued every year, for the benefit of his countrymen, in the annual publication known as "Poor Richard's Almanac." It is very interesting at this distance of time to read the homely practical rules laid down by this great philosopher and statesman; and, though some modifications have been suggested by the experience of a hundred and thirty years, especially as regards the dimensions of the lightning conductor, it is surprising to find how accurately the general principles of its construction, and of its action, are here set forth.

"It has pleased God," he says, "in His goodness to mankind, at length to discover to them the means of securing their habitations and other buildings from mischief by thunder and lightning. The method is this: Provide a small iron rod, which may be made of the rod-iron used by nailors, but of such a length that one end being three or four feet in the moist ground, the other may be six or eight feet above the highest part of the building. To the upper end of the rod fasten about a foot of brass wire, the size of a common knitting needle, sharpened to a fine point; the rod may be secured on the house by a few small staples. If the house or barn be long, there may be a rod and point at each end, and a middling wire along the ridge from one to the other. A house thus furnished will not be damaged by lightning, it being attracted by the points and passing through the metal into the ground, without hurting anything. Vessels also having a sharp-pointed rod fixed on the top of their masts, with a wire from the foot of the rod reaching down round one of the shrouds to the water, will not be hurt by lightning."

Introduction of Lightning Rods into England.—The progress of lightning conductors was more slow in England and on the Continent of Europe, owing to a fear, not unnatural, that they might, in some cases, draw down the lightning where it would not otherwise have fallen. People preferred to take their chance of escaping as they had escaped before, rather than invite, as it were, the lightning to descend on their houses, in the hope that an iron rod would convey it harmless to the earth. But the immense amount of damage done every year by lightning, soon led practical men to entertain a proposal which offered complete immunity from all danger on such easy terms; and when it was found that buildings protected by lightning conductors were, over and over again, struck by lightning without suffering any harm, a general conviction of their utility was gradually established in the public mind.

The first public building protected by a lightning rod in England was St. Paul's Cathedral, in London. On the eighteenth of June, 1764, the beautiful steeple of Saint Bride's Church, in the city, was struck by lightning and reduced to ruin. This incident awakened the attention of the dean and chapter of St. Paul's to the danger of a similar calamity, which seemed, as it were, impending over their own church. After long deliberation, they referred the matter to the Royal Society, asking for advice and instruction. A committee of scientific men was appointed by the Royal Society to consider the question. Benjamin Franklin himself, who happened to be in London at the time, as the representative of the American States in their dispute with England, was nominated a member of the committee. And the result of its deliberation was that, in the year 1769, a number of lightning conductors were erected on St. Paul's Cathedral.

It was on this occasion that arose the celebrated controversy about the respective merits of points and balls. Franklin had recommended a pointed conductor; but some members of the committee were of opinion that the conductor should end in a ball and not in a point. The decision of the committee was in favor of Franklin's opinion, and pointed conductors were accordingly adopted for St. Paul's Cathedral. But the controversy did not end here. The time was one of great political excitement, and party spirit infused itself even into the peaceful discussions of science. The weight of scientific opinion was on the side of Franklin; but it was hinted, on the other side, that the pointed conductors were tainted with republicanism, and pregnant with danger to the empire. As a rule, the whigs were strongly in favor of points; while the Tories were enthusiastic in their support of balls.

For a time the Tories seemed to prevail. The king was on their side. Experiments on a grand scale were conducted in his presence, at the Pantheon, a large building in Oxford street; he was assured that these experiments proved the great superiority of balls over points; and to give practical effect to his convictions, his majesty directed that a large cannon ball should be fixed on the end of the lightning conductor attached to the royal palace at Kew. But the committee of the Royal Society remained unconvinced. In course of time the heat of party spirit abated; experience as well as reason was found to be in favor of Franklin's views; and the battle of the balls and points has long since passed into the domain of history.[1]

Functions of a Lightning Conductor.—A lightning conductor fulfills two functions. First, it favors a silent and gradual discharge of electricity between the cloud and the earth, and thus tends to prevent that accumulation which must of necessity take place before a flash of lightning will pass. Secondly, if a flash of lightning come, the lightning conductor offers it a safe channel through which it may pass harmless to the earth.

These two functions of a lightning conductor may be easily illustrated by experiment. When our machine is in action, if I present my closed hand to the large brass conductor, a spark passes between them, and I feel, at the same moment, a slight electric shock. Here the conductor of the machine, as usual, holds the place of the electrified cloud; my closed hand represents, as it were, a lofty building that stands out prominently on the surface of the earth; the spark is the flash of lightning, and the electric shock just suggests the destructive power of the sudden disruptive discharge.

Now let me protect this building by a lightning conductor. For this purpose, I take in my hand a brass rod, which I connect with the earth by a brass chain. In the first instance, I will have a metal ball on the end of my lightning conductor. You see the effect; sparks pass rapidly, but I feel no shock. I can increase the strength of the discharge by hanging this condensing jar on the conductor of the machine. Sparks pass now, much more brilliant and powerful than before, but still I get no shock. It is evident, therefore, that my lightning rod does not prevent the flash from passing, but it conveys it harmless to the ground.

[1] See Philosophical Transactions of the Royal Society, 1773, p. 42, and 1778, part i., p. 232; Anderson's Lightning Conductors, pp. 40–2; Lightning Rod Conference, pp. 76–9.

I next take a rod which is sharply pointed, and connecting it as before with the earth by a brass chain, I present the sharp point to the conductor of the machine. Observe how different is the result; there is no disruptive discharge; no spark passes; no shock is felt. Electricity still continues to be generated in the machine, and electricity is generated, by induction, in the brass rod, and in my body. But these two opposite electricities discharge themselves silently, by means of this pointed rod, and no sensible effect of any kind is exhibited.

These experiments are very simple, but they really put before us, in the clearest possible way, the whole theory of lightning conductors. In particular, they give us ocular demonstration that an efficient lightning rod not only makes the lightning harmless when it comes, but tends very much to prevent its coming. A remarkable example, on a large scale, of this important property, is furnished by the town of Pietermaritzburg, the capital of the colony of Natal, in South Africa. This town is subject to the frequent visitation of thunderstorms, at certain seasons of the year, and much damage was formerly done by lightning, but since the erection of lightning conductors on the principal buildings, the lightning has never fallen within the town. Thunderclouds come as before, but they pass silently over the city, and only begin to emit their lightning flashes when they reach the open country, and have passed beyond the range of the lightning conductors.[1]

But it will often happen, even in the case of a pointed conductor, that the accumulation of electricity goes on so fast that the silent discharge is insufficient to keep it in check. A disruptive discharge will then take place, from time to time, and a flash of lightning will pass. Under these circumstances, the lightning conductor is called upon to fulfill its second function, and to convey the lightning harmless to the earth.

Conditions of a Lightning Conductor.—From the consideration of the functions which it has to fulfill, we may now infer what are the conditions necessary for an efficient lightning conductor. The first condition is that the end of the conductor, projecting into the air, should have, at least, one sharp point. Our experiments have shown us that a pointed conductor tends, in a manner, to suppress the flash of lightning altogether; whereas a blunt conductor, or one ending in a ball, tends only to make it harmless when it comes. It is evident, therefore, that the pointed conductor offers the greater security.

But a fine point is very liable to be melted when the lightning falls upon it, and thus to be rendered less efficient for future service. To meet this danger, it has recently been suggested, by the Lightning Rod Conference, that the extreme end of the conductor should be a blunt point, destined to receive the full force of the lightning flash,

[1] See A Lecture on Thunderstorms, by Professor Tait of Edinburgh, published in Nature, vol. xxii., p. 365.

when it comes; and that, a little lower down, a number of very fine points should be provided, with a view to favor the silent discharge. This suggestion, which appears admirably fitted to provide for the twofold function of a lightning conductor, deserves to be recorded in the exact terms of the official report.

"It seems best to separate the double functions of the point, prolonging the upper terminal to the very summit, and merely beveling it off, so that, if a disruptive discharge does take place, the full con-conducting power of the rod may be ready to receive it. At the same time, having regard to the importance of silent discharge from sharp points, we suggest that, at one foot below the extreme top of the upper terminal, there be firmly attached, by screws and solder, a copper ring bearing three or four copper needles, each six inches long, and tapering from a quarter of an inch diameter to as fine a point as can be made; and with the object of rendering the sharpness as permanent as possible, we advise that they be platinized, gilded, or nickel plated."[1]

The second condition of a lightning conductor is, that it should be made of such material, and of such dimensions, as to offer an easy passage to the greatest flash of lightning likely to fall on it; otherwise it might be melted by the discharge, and the lightning, seeking for itself another path, might force its way through bad conductors, which it would partly rend asunder, and partly consume by fire. Copper is now generally regarded as the best material for lightning conductors, and it is almost universally employed in these countries. If it is used in the form of a rope, it should not be less than half an inch in diameter; if a band of copper is preferred—and it is often found more convenient by builders—it should be about an inch and a half broad and an eighth of an inch thick. In France it has been hitherto more usual to employ iron rods for lightning conductors, but since iron is much inferior to copper in its conducting power, the iron rod must be of much larger dimensions; it should be at least one inch in diameter.[2]

The third condition is that the lightning conductor should be continuous throughout its whole length, and should be placed in good electrical contact with the earth. This is a condition of the first importance, and experience has shown that it is the one most likely of all to be neglected. In a large town the best earth connection is furnished by the system of water-mains and gas-mains, each of which constitutes a great network of conductors everywhere in contact with

[1] Report of the Lightning Rod Conference, p. 4.

[2] The dimensions here set forth are greater in some respects than those "recommended as a minimum" in the report of the Lightning Rod Conference, page 6. But it will be observed by those who consult the report that the minimum recommended is just the size which, in the preceding paragraph of the report, is said to have been actually melted by a flash of lightning; and, therefore, it seems not to be a very safe minimum. It will be also seen that there is some confusion in the figures given, and that they contradict one another. For the dimensions of iron rods, see the instructions adopted by the Academy of Science, Paris, May 20, 1875; Lightning Rod Conference, pp. 67–8.

the earth. Two points, however, must be carefully attended to—first, that the electrical contact between the lightning conductor and the metal pipe should be absolutely perfect; and, secondly, that the pipe selected should be of such large dimensions as to allow the lightning an easy passage through it to the principal main.

If no such system of water-pipes or gas-pipes is at hand, then the lightning rod should be connected with moist earth by means of a bed of charcoal or a metal plate not less than three feet square. This metal plate should be always of the same material as the conductor, otherwise a galvanic action would be set up between the two metals, which in course of time might seriously damage the contact. Dry earth, sand, rock, and shingle are bad conductors; and, if such materials exist near the surface of the earth, the lightning rod must pass through them and be carried down until it reaches water or permanently damp earth.

Mischief Done by Bad Conductors.—If the earth contact is bad, a lightning conductor does more harm than good. It invites the lightning down upon the building without providing for it, at the same time, a free passage to earth. The consequence is that the lightning forces a way for itself, violently bursting asunder whatever opposes its progress, and setting fire to whatever is combustible.

I will give you some recent and striking examples. In the month of May, 1879, the church of Laughton-en-le-Morthen, in England, though provided with a conductor, was struck by lightning and sustained considerable damage. On examination it was found that the lightning followed the conductor down along the spire as far as the roof; then, changing its course, it forced its way through a buttress of massive masonwork, dislodging about two cartloads of stones, and leaped over to the leads of the roof, about six feet distant. It now followed the leads until it came to the cast-iron down-pipes intended to discharge the rain-water, and through these it descended to the earth. When the earth contact of the lightning conductor was examined, it was found exceedingly deficient. The rod was simply bent underground, and buried in dry loose rubbish at a depth not exceeding eighteen inches. This is a very instructive example. The lightning had a choice of two paths—one by the conductor prepared for it, the other by the leads of the roof and the down-pipes—and, by a kind of instinct which, however we may explain, we must always contemplate with wonder, it chose the path of least resistance, though in doing so it had to burst its way at the outset through a massive wall of solid masonry.[1]

On the 5th of June, in the same year, a flash of lightning struck the house of Mr. Osbaldiston, near Sheffield, and, notwithstanding the supposed protection of a lightning conductor, it did damage to the

[1] See letter of Mr. R. S. Newall, F. R. S., in the *Times*, May 30, 1879.

amount of about five hundred pounds. The lightning here followed the conductor to a point about nine feet from the ground, then passed through a thick wall to a gas-pipe at the back of the drawing-room mirror. It melted the gas-pipe, set fire to the gas, smashed the mirror to atoms, broke the Sevres vases on the chimney-piece, and dashed the furniture about. In this case, as in the former, it was found that the earth contact was bad; and, in addition, the conductor itself was of too small dimensions. Hence, the electric discharge found an easier path to earth through the gas-pipes, though to reach them it had to force for itself a passage through a resisting mass of non-conductors.[1]

Again in the same year, on the 28th of May, the house of Mr. Tomes, of Caterham, was struck by lightning, and some slight damage was done. After a careful examination it was found that the greater part of the discharge left the lightning conductor with which the house was provided, and passed over the slope of the roof to an attic room, into which it forced its way through a brick wall, and reached a small iron cistern. This cistern was connected by an iron pipe of considerable dimensions with two pumps in the basement story; and through them the lightning found an easy passage to the earth, and did but little harm on its way. When the earth contact of the lightning conductor was examined, it was discovered that the end of the rod was simply stuck into a dry chalky soil to a depth of about twelve inches. Thus in this case, as in the two former, it was made quite clear that the lightning conductor failed to fulfill its functions because the earth contact was bad.[2]

Cases are not uncommon in which builders provide underground a carefully constructed reservoir of water, into which the lower end of the lightning rod is introduced. The idea seems to prevail that a reservoir of water constitutes a good earth contact; and this is quite true of a natural reservoir, such as a lake, where the water is in contact with moist earth over a considerable area. But an artificial reservoir may have quite an opposite character, and practically insulate the lightning conductor from the earth. One which came under my notice lately, in the neighborhood of this city, consists of a large earthenware pipe set on end in a bed of cement, and kept half full of water. Now, the earthenware pipe is a good insulator, and so is the bed of cement in which it rests; and the whole arrangement is identical, in all essential features, with the apparatus of Professor Richman, in which he introduced his lightning rod into a glass bottle, and by which he lost his life a hundred and thirty years ago.

A conductor mounted in this manner will, probably enough, draw down lightning from the clouds; but it is more likely to discharge it, with destructive effect, into the building it is intended to guard, than to transmit it harmlessly to the earth. An example is at hand in the

[1] See Nature, June 12, 1879, vol. xx., p. 146.
[2] See letter of Mr. Tomes in Nature, vol. xx., p. 145; also Lightning Rod Conference, pp. 210–15.

case of Christ Church, in the town of Clevedon, in Somersetshire. This church was provided with a very efficient system of lightning conductors, five in number, corresponding to the four pinnacles and the flagstaff, on the summit of the principal tower. The five conductors consisted of good copper-wire rope; all were united together inside the tower, through which they were carried down to earth, and there ended in an earthenware drain. This kind of earth contact might be pretty good as long as water was flowing in the drain; but whenever the drain was dry the conductor was practically insulated from the earth. On the fifteenth of March, 1876, the church was struck by lightning, which for some distance followed the line of the conductor; then finding its passage barred by the earthenware drain, which was dry at the time, it burst through the walls of the church, displacing several hundredweight of stone, and making its way to earth through the gas-pipe.[1]

Another very instructive example is furnished by the lightning conductor attached to the lighthouse of Berehaven, on the south-west coast of Ireland. It consists of a half-inch copper-wire rope, which is carried down the face of the tower "until it reaches the rock at it base, where it terminates in *a small hole, three inches by three inches, jumped out of the rock, about six inches under the surface.*" Here, again, we have a good imitation of Professor Richman's experiment, with only this difference, that a small hole in the rock is substituted for a glass bottle. A lightning conductor of this kind fulfills two functions: it increases the chance of the lightning coming down on the building, and it makes it positively certain that, having come, it cannot get to earth without doing mischief.

The lightning did come down on the Berehaven Lighthouse, about five years ago. As might have been expected, it made no use of the lightning conductor in finding a path to earth, but forced its way through the building, dealing destruction around as it descended from stage to stage. The Board of Irish Lights furnished a detailed report of this accident to the Lightning Rod Conference, in March, 1880, from which the above particulars have been derived.[2]

Precaution Against Rival Conductors.—But it is not enough to provide a good lightning conductor, which is itself able to convey the electric discharge harmless to the earth; we must take care that there are no rival conductors near at hand in the building, to draw off the lightning from the path prepared for it, and conduct it by another route in which its course might be marked with destruction. This precaution is of especial importance at the present day, owing to the great extent to which metal, of various kinds, is employed in the construction and fittings of modern buildings. I will take a typical case which will bring home this point clearly to your minds.

[1] See Anderson, Lightning Conductors, pp. 208–10.
[2] See Lightning Rod Conference, pp. 208–10; see also the note at the end of this Lecture, p. 52.

A great part of the roof of many large buildings is covered with lead. The lead, at one or more points may come near the gutters intended to collect the rain water; the gutters are in connection with the cast-iron down-pipes into which the water flows, and these down-pipes often pass into the earth, which, under the circumstances, is generally moist, and, therefore, in good electrical contact with the metal pipes. Here, then, is an irregular line of conductors, which, though it has gaps here and there, may, under certain conditions, offer to the lightning discharge a path not less free than the lightning conductor itself. What is the consequence? The flash of lightning, or a part of it, will quit the lightning rod, and make its way to earth through the broken series of conductors, doing, perhaps, serious mischief, as it leaps across, or bursts asunder, the non-conducting links in the chain.

Another illustration may be taken from the gas and water-pipes, with which almost all buildings in great cities are now provided, and which constitute a network of conductors, spreading out over the walls and ceilings, and stretching down into the earth, with which they have the best possible electrical contact. Now, it often happens that a lightning conductor, at some point in its course, comes within a short distance of this network of pipes. In such a case, a portion of the electrical discharge is apt to leave the lightning conductor, force its way destructively through masses of masonry, enter the network of pipes, melt the leaden gas-pipe, ignite the gas, and set the building on fire.

These are not merely the speculations of philosophers. All the various incidents I have just described have occurred, over and over again, during the last few years. You will remember, in some of the examples I have already set before you, when the electric discharge failed to find a sufficient path to earth through the lightning rod, it followed some such broken series of chance conductors as we are now considering. But this broken series of conductors seems to bring with it a special danger of its own, even when the lightning conductor is otherwise in efficient working order. I will give you just one case in point.

On the fifth of June, 1879, the Church of Saint Marie, Rugby, was struck by lightning and set on fire, and narrowly escaped being burned to the ground. A number of workmen were engaged on that day in repairing the spire of the church. About three o'clock they saw a dense black cloud approaching, and they came down to take shelter within the building. In a few minutes they heard a terrific crash just overhead; at the same moment the gas was lighted under the organ loft and the woodwork was set in a blaze. The men soon succeeded in putting out the fire, and the church escaped with very little damage.

Now, in this case there was no reason to suppose that the lightning conductor was in any way defective. But about half-way up the spire there was a peal of eight bells. Attached to these bells were iron wires, about the eighth of an inch in diameter, leading from the clappers down to the organ-loft, where they came within a short distance of a gas-pipe fixed in the wall. It would seem that a great part of the discharge was carried safely to earth by the lightning conductor. But a part branched off at the bells in the spire, descended by the iron wires, and forced its way into the organ loft, to reach the network of gas-pipes, through which it passed down to the earth, melting the soft leaden gas-pipe in its course and lighting the gas.

The remedy for this danger is obvious. All large masses of metal used in the structure of a building—the leads and gutters of the roof, the cast-iron down-pipes, the iron gas and water mains—should be put in good metallic connection with the lightning conductor, and, as far as may be, with one another. Connected in this way they furnish a continuous and effective line of conductors leading safely down to earth ; and, instead of being a dangerous rival, they become a useful auxiliary to the lightning rod.

I would observe, however, that the lightning conductor ought not to be connected directly with the soft leaden pipes which are commonly employed to convey gas and water to the several parts of a building. Such pipes, as we have seen, are liable to be melted when any considerable part of the lightning discharge passes through them ; and thus much harm might be done, and the building might even be set on fire by the lighting of the gas. Every good end will be attained if the conductor is put in metallic connection with the iron gas and water *mains* either inside or outside the building.

Insulation of Lightning Conductors.—It is a question often asked whether a lightning rod should be insulated from the building it is intended to protect. I believe that this practice was formerly recommended by some writers, and I have observed that glass insulators are still employed not infrequently by builders in the erection of lightning conductors ; but, from the principles I have set before you today, it seems clear that any insulation of this kind is, to say the least, altogether useless. The building to be protected is itself in electrical communication with the earth, and the lightning conductor, if efficient, is also in electrical communication with the earth—therefore, the lightning conductor and the building are in electrical communication with each other through the earth, and any attempt at insulating them from one another above the earth is only labor thrown away.

Further, I have just shown you that the masses of metal employed in the structure or decoration of a building ought to be electrically connected with each other and with the lightning conductor. Now, if this be done, the lightning conductor is, by the fact, in direct communication with the building, and the glass insulators are utterly futile. Again, the building itself, during a thunderstorm, becomes highly electrified by the inductive action of the cloud, and needs to be discharged through the conductor just as the surrounding earth needs to be discharged; therefore, the more thoroughly it is connected with the conductor, the more effectively will the conductor fulfill its functions.

Personal Safety in a Thunderstorm.—I suppose there is hardly any one to whom the question has not occurred, at some time or another, what he had best do to secure his personal safety during a thunderstorm. This question is of so much practical interest that I think I shall be excused if I say a few words about it, though perhaps, strictly speaking, it is somewhat beside the subject of lightning conductors.

At the outset, perhaps, I shall surprise you when I say that you would enjoy the most perfect security if you were in a chamber entirely composed of metal plates, or in a cage constructed of metal bars, or if you were incased, like the knights of old, in a complete suit of metal armor. This kind of defense is looked upon as so perfect, among scientific men, that Professor Tait does not hesitate to recommend his adventurous young friends devoted to the cause of science to provide themselves with a light suit of copper, and, thus protected, take the first opportunity of plunging into a thundercloud, there to investigate, at its source, the process by which lightning is manufactured.[1]

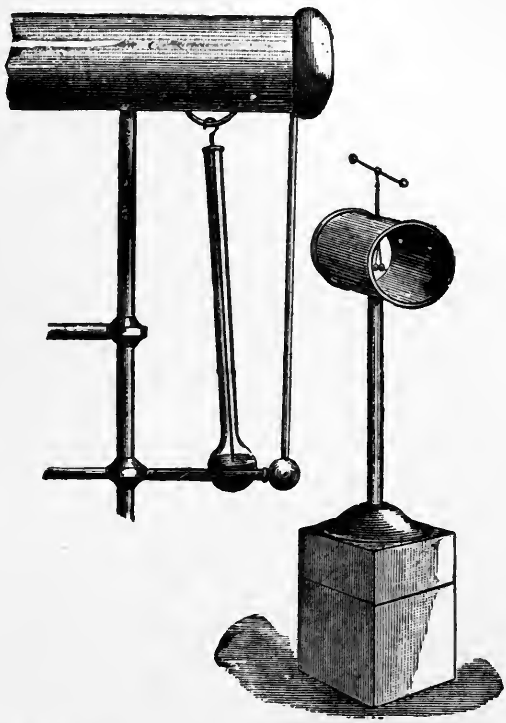
The reason why a metal covering affords complete protection is that, when a conductor is electrified, the whole charge of electricity exists on the outside surface of the conductor; and therefore, when a discharge takes place, it is only the outside surface that is affected. Thus, if you were completely incased in a metal covering, and then charged with electricity by the inductive action of a thundercloud, it is only the metal covering that would undergo any change of electrical condition; and when the lightning flash would pass, it is only the metal covering that would be discharged.

Let me show you a very pretty and interesting experiment to illustrate this principle: Here is a hollow brass cylinder, open at the ends, mounted on an insulating stand. On the outside is erected a light brass rod with two pith balls suspended from it by linen threads. Two pith balls are also suspended by linen threads from the inner surface of the cylinder. You know that these pith balls will indicate to us the electrical condition of the surfaces to which they are attached. If the surface be electrified, the pith balls attached to it will share in its electrical condition, and will repel each other; if the surface be neutral, the pith balls attached to it will be neutral, and will remain at rest.

[1] Lecture on Thunderstorms, Nature, vol. xxii., pp. 365, 437. See, also, a very interesting paper by the late Professor J. Clerk Maxwell, read before the British Association at Glasgow in 1876, and reprinted in the report of the Lightning Rod Conference, pp. 109, 110.

I now put this apparatus under the influence of our thundercloud, that is, the large brass conductor of our machine. The moment my assistant turns the handle, the electricity begins to be developed on the conductor, and you see, at once, the effect on the brass cylinder. The pith balls attached to the outer surface fly asunder; those attached to the inner surface remain at rest. And now a spark passes; our thundercloud is discharged; the inductive action ceases; the pith balls on the outside suddenly collapse, while those on the inside are in no way affected.

It is not necessary that the brass cylinder should be insulated. To



PROTECTION FROM LIGHTNING FURNISHED BY A CLOSED CONDUCTOR.

vary the experiment, I will now connect it with the earth by a chain; you will observe that the effect is precisely the same as before. Flash after flash passes while the machine continues in action; the outside pith balls fly about violently, being charged and discharged alternately; the inside pith balls remain all the time at rest. Thus you see clearly that, if you were sitting inside such a metal chamber as this, or covered with a complete suit of metal armor, you would be perfectly secure during a thunderstorm, whether the chamber were electrically connected with the earth or insulated from it.

Practical Rules.—But it rarely happens, when a thunderstorm comes, that an iron hut or a complete suit of armor is at hand, and you will naturally ask me what you ought to do under ordinary circumstances. First, let me tell you what you ought not to do. You ought not to take shelter under a tree, or under a haystack, or under the lee of a house; you ought not to stand on the bank of a river, or close to a large sheet of water. If indoors, you ought not to stay near the fireplace, or near any of the flues or chimneys; you ought not to stand under a gasalier hanging from the ceiling; you ought not to remain close to the gas pipes or water-pipes, or any large masses of metal, whether used in the construction of the building, or lying loosely about.

The necessity for these precautions is sufficiently evident from the principles I have already put before you. You want to prevent your body from becoming a link in that broken chain of conductors which, as we have seen, the electric discharge between earth and cloud is likely to follow. Now a tree is a better conductor than the air; and your body is a better conductor than a tree. Hence, the lightning, in choosing the path of least resistance, would leave the air to pass through the tree, and would leave the tree to pass through you. A like danger would await you if you stood under the lee of a haystack or of a house.

The number of people who lose their lives by taking refuge under trees in thunderstorms is very remarkable. As one instance out of many, I may cite the following case which was reported in the *Times*, July 14, 1887: "Yesterday the funeral of a negress was being conducted in a graveyard at Mount Pleasant, sixty miles north of Nashville, Tennessee, when a storm came on, and the crowd ran for shelter under the trees. Nine persons stood under a large oak, which the lightning struck, killing everyone, including three clergymen, and the mother and two sisters of the girl who had been buried."

Again, every large sheet of water constitutes practically a great conductor, which offers a very perfect medium of discharge between the earth round about and the cloud. Therefore, when a thundercloud is overhead, the sheet of water is likely to become one end of the line of the lightning discharge; and if you be standing near it, the line of discharge may pass through your body.

When lightning strikes a building, it is very apt to use the stack of chimneys in making its way to earth, partly because the stack of chimneys is generally the most prominent part of the building, and partly because, on account of the heated air and the soot within the chimney, it is usually a moderately good conductor. Therefore, if you be indoors, you must keep well away from the chimneys; and for a similar reason, you must keep as far as you can from large masses of metal of every kind.

Having pointed out the sources of danger which you must try to avoid in a thunderstorm, I have nearly exhausted all the practical advice that I have at my command. But there are some occasions on which it may be possible, not only to avoid evident sources of danger, but to make special provision for your own security. Thus, for example, in the open country, if you stand a short distance from a wood, you may consider yourself as practically protected by a lightning conductor. For a wood, by its numerous branches and leaves, favors very much a quiet discharge of electricity, thus tending to suppress altogether the flash of lightning; and if the flash of lightning does come, it is much more likely to strike the wood than to strike you, because the wood is a far more prominent body, and offers, on the whole, an easier path to earth. In like manner, if you place yourself near a tall solitary tree, some twenty or thirty yards outside its longest branches, you will be in a position of comparative safety. If the storm overtake you in the open plain, far away from trees and buildings, you will be safer lying flat on the ground than standing erect.

In an ordinary dwelling house, the best situation is probably the middle story, and the best position in the room is in the middle of the floor; provided, of course, that there is no gasalier hanging from the ceiling above or below you. Strictly speaking, the *middle of the room* would be a still safer position than the middle of the floor; and nothing could be more perfect than the plan suggested by Franklin, to get into "a hammock, or swinging bed, suspended by silk cords, and equally distant from the walls on every side, as well as from the ceiling and floor, above and below." An interesting case has been recently recorded, by a resident of Venezuela, which illustrates in a remarkable way the excellence of this advice. "The lightning," he says, "struck a *rancho*—a small country house, built of wood and mud, and thatched with straw or large leaves—where one man slept in a hammock, another lay under the hammock on the ground, and three women were busy about the floor; there were also several hens and a pig. The man in the hammock did not receive any injury whatever, while the other four persons and the animals were killed."[1]

But, as I can hardly hope that many of you when the thunderstorm actually comes will find yourselves provided with a hammock, I would recommend, as more generally useful, another plan of Franklin's, which is simply to sit on one chair in the middle of the floor and put your feet up on another. This arrangement will approach very nearly to absolute security if you take the further precaution, also mentioned by Franklin, of putting a feather bed or a couple of hair mattresses under the chairs.[2]

[1] Nature, vol. xxxi., p. 459.
[2] See further information on this interesting subject in the Report of the Lightning Rod Conference, pp. 233-5.

Security Afforded by Lightning Rods.—You might, perhaps, be inclined to infer hastily, from the examples I have set before you, in the course of this lecture, of buildings which were struck and severely injured by lightning though provided with lightning conductors, that a lightning rod affords a very imperfect protection to life and property. But such an idea would be entirely at variance with the evidence at hand on the subject. In all the cases to which I have referred, and in many others which might easily have been cited, the damage was done simply because the lightning rods were deficient in one or more of the conditions on which I have so much insisted. Where these conditions are fulfilled, the lightning flash will either not come down at all upon the building, or, if it do come, it will be carried harmless to the earth.

Perhaps there is no one fact that so forcibly brings home to the mind the complete protection afforded by lightning conductors as the change which followed their introduction into the Royal Navy. I have already told you that in former times the damage done by lightning to ships of the Royal Navy was a regular source of expenditure, amounting every year to several thousand pounds sterling. But, after the general adoption of lightning conductors about forty years ago, through the indefatigable exertions of Sir William Snow Harris, this source of expenditure absolutely disappeared, and injury to life and property has long been practically unknown in Her Majesty's Fleet.

I should say, however, that the trial of lightning conductors in the Navy, though it lasted long enough to prove their perfect efficiency, has almost come to an end in our own days. The great iron monsters which in recent times have taken the place of the wooden ships of Old England are quite independent of lightning rods in the common sense of the word. Their ponderous masts are virtually lightning rods of colossal dimensions, and their unsightly hulls are, so to speak, earth-plates of enormous size in perfect electrical contact with the ocean. To add to such structures lightning conductors of the common kind would be nothing better than "wasteful and ridiculous excess."

As regards buildings on land, I may refer to the little province of Schleswig-Holstein, of which I have already spoken to you. From some cause or other this small peninsula is singularly exposed to thunderstorms, and of late years it has been more abundantly provided with lightning conductors than, perhaps, any other district of equal extent in Europe. Now, as a simple illustration of the protection afforded by these lightning conductors, I may mention that, on the 26th of May, 1878, a violent thunderstorm burst over the little town of Utersen. Five several flashes of lightning fell in different parts of the town, but not the slightest harm was done, each flash being safely carried to earth by a lightning conductor. Further, it appears from the records of the fire insurance company that, out of 552 buildings injured by lightning during a period of eight years—from 1870 to 1878—only four had lightning conductors; and in these four cases it was found, on examination, that the lightning conductors were defective.[1]

It would be easy to multiply evidence on this subject. But as I have already trespassed, I fear, too far on your patience, I will content myself with saying, in conclusion, that according to all the highest authorities, both practical and theoretical, any structure provided with a lightning conductor properly fitted up in conformity with the principles I have set before you to-day is perfectly secure against lightning. The lightning, indeed, may fall upon it, but it will pass harmless to the earth; and the experience of more than a hundred years has fully justified the simple and modest words of the great inventor of lightning conductors: "It has pleased God, in His goodness to mankind, at length to discover to them the means of securing their habitations and other buildings from mischief by thunder and lightning."

NOTE I.

ON THE LIGHTNING CONDUCTOR AT BEREHAVEN.[2]

It is satisfactory to know that the lightning conductor referred to in my lecture as attached to the lighthouse at Berehaven has been put in good order under the best scientific guidance. The following interesting letter from Professor Tyndall, which appeared in the *Times*, August 31, 1887, gives the history of the matter very clearly, and fully bears out the views put forward in my lecture:

"Your recent remarks on thunderstorms and their effects induce me to submit to you the following facts and considerations. Some years ago a rock lighthouse on the coast of Ireland was struck and damaged by lightning. An engineer was sent down to report on the occurrence; and, as I then held the honorable and responsible post of scientific adviser to the Trinity House and Board of Trade, the report was submitted to me. The lightning conductor had been carried down the lighthouse tower, its lower extremity being carefully embedded in a stone perforated to receive it. If the object had been to invite the lightning to strike the tower, a better arrangement could hardly have been adopted.

"I gave directions to have the conductor immediately prolonged, and to have added to it a large terminal plate of copper, which was to be completely submerged in the sea. The obvious convenience of a chain as a prolongation of the conductor caused the authorities in Ireland to propose it; but I was obliged to veto the adoption of the chain. The contact of link with link is never perfect. I had, moreover, beside me a portion of a chain cable through which a lightning discharge had passed, the electricity in passing from link to link encountering a resistance sufficient to enable it to partially fuse the chain. The abolition of resistance is absolutely necessary in connecting a lightning conductor with the earth, and this is done by closely embedding in the earth a plate of good conducting material and of large area. The largeness of area makes atonement for the imperfect conductivity of earth. The plate, in fact, constitutes

[1] See "Die Theorie, die Anlage, und die Prüfung der Blitzableiter," von Doctor W. Holtz, Griefswald, 1878.
[2] See page 44.

a wide door through which the electricity passes freely into the earth, its disruptive and damaging effects being thereby avoided.

"These truths are elementary, but they are often neglected. I watched with interest some time ago the operation of setting up a lightning conductor on the house of a neighbor of mine in the country. The wire rope which formed part of the conductor was carried down the wall and comfortably laid in the earth below without any terminal plate whatever. I expostulated with the man who did the work, but he obviously thought he knew more about the matter than I did. I am credibly informed that this is a common way of dealing with lightning conductors by ignorant practitioners, and the Bishop of Winchester's palace at Farnham has been mentioned to me as an edifice 'protected' in this fashion. If my informant be correct, the 'protection' is a mockery, a delusion, and a snare."

NOTE II.

BOOKS OF REFERENCE.

As some of my readers may wish to pursue the study of lightning and lightning conductors beyond the limits to which a popular lecture must, of necessity, be confined, I subjoin a list of the books which I think they would be likely to find most useful for the purpose. Among ordinary text-books on physics—Jamin, Cours de Physique, vol. i., pp. 470–494; Mascart, Traité d'Electricité Statique, vol. ii., pp. 555–579; De Larive, A Treatise on Electricity, in three volumes, London, 1853–8, vol. iii., pp. 90–201; Daguin, Traité de Physique, vol. iii., pp. 209–280; Riess, Die Lehre von der Reibungs-Elektricität, vol. ii., pp. 494–564; Müller-Pouillet, Lehrbuch der Physik, Braunschweig, 1881, vol. iii., pp. 210–225; Scott, Elementary Meteorology, chap. x. Of the numerous special treatises and detached papers on the subject, I would recommend Instruction sur les Paratonnerres adopté par l'Académie des Sciences, Part i., 1823, Part ii., 1854, Part iii., 1867, Paris, 1874; Arago, Sur le Tonnerre, Paris, 1837; also his Meteorological Essays, translated by Sabine, London, 1855; Sir William Snow Harris, On the Nature of Thunderstorms, London, 1843; also by the same writer, A Treatise on Frictional Electricity, London, 1867; and various papers on lightning conductors, from 1822 to 1859; Tomlinson, The Thunderstorm, London, 1877; Anderson, Lightning Conductors, London, 1880; Holtz, Ueber die Theorie, die Anlage, und die Prüfung der Blitzableiter, Greifswald, 1878; Weber, Berichte über Blitzschläge in der Provinz Schleswig-Holstein, Kiel, 1880–1; Tait, A Lecture on Thunderstorms, delivered in the City Hall, Glasgow, in 1880, Nature, vol. xxii.; Report of the Lightning Rod Conference, London, 1882. This last-mentioned volume comes to us with very high authority, representing, as it does, the joint labors of several eminent scientific men selected from the following societies: The Meteorological Society, the Royal Institute of British Architects, the Society of Telegraph Engineers and Electricians, the Physical Society.

Since the above was in print, two lectures given before the Society of Arts by Professor Oliver Lodge, F. R. S., have appeared in the *Electrician*, June and July, 1888, in which some new views are put forward respecting lightning conductors, that seem deserving of careful consideration.

APPENDIX.

RECENT CONTROVERSY ON LIGHTNING CONDUCTORS.

THE lecture on lightning conductors contained in this volume fairly represents, I think, the theory hitherto received on the subject. It is, moreover, entirely in accord with the report of the Lightning Rod Conference, brought out in 1883, by a committee of most eminent men, representing several branches of science, who were specially chosen to consider this question some ten years ago.

Lectures of Professor Lodge.—But, in the month of March, 1888, two lectures were given before the Society of Arts, in London, by Professor Oliver Lodge, in which this theory was directly challenged, and attacked with cogent arguments, supported by striking and original experiments. These lectures gave rise to an animated controversy, which culminated in a formal discussion at the recent meeting of the British Association in Bath. The discussion was carried on with great spirit, and most of the leading representatives of physical and mechanical science took an active part in it. The greater portion of this volume was printed off before the meeting of the British Association took place. But the discussion on the theory of lightning conductors seemed to me so interesting and important that I thought it right, in the form of an Appendix, to give some account of the questions at issue, and of the opinions expressed upon them.

Professor Lodge maintains[1] that the received theory of lightning rods is open to two objections. First, it takes account only of the conducting power of the lightning rod, and takes no account of the phenomenon known as self-induction, or electrical inertia. Secondly, it assumes that the whole substance of a lightning rod acts as a conductor, in all cases of lightning discharge; whereas there is reason to believe that, in many cases, it is only a thin outer shell that really comes into action. I will deal with these two points separately.

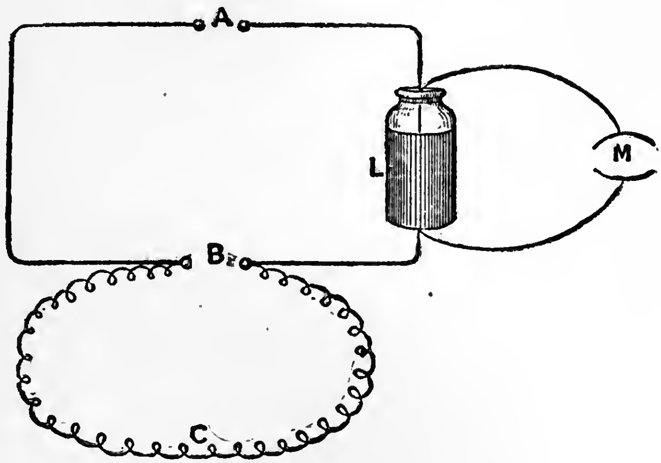
The Effect of Self-Induction.—When an electric discharge begins to pass through a conductor, a momentary back electro-motive force is developed in the conductor, which obstructs its passage. This phenomenon is called by some self-induction, by others electrical inertia; but its existence is admitted by all. Now, when a flash of lightning, so to say, falls on a lightning rod, the back electro-motive

[1] See his Lectures, published in the *Electrician*, June 22, June 29, July 6, and July 13, 1888.

force developed is very considerable; and it may offer so great an obstruction that the discharge will find an easier passage by some other route, such as the stone walls and woodwork, and furniture of the building.

According to this view, the obstruction which a flash of lightning encounters in a conductor consists partly of the resistance of the conductor, in the ordinary sense of the word resistance, and partly of the back electro-motive force due to self-induction. The sum of these two Professor Lodge calls the *impedance* of the lightning rod; and he considers that the impedance may be enormously great, even when the resistance, in the ordinary sense, is comparatively small.

In support of this view he has devised the following extremely ingenious and remarkable experiment. A large Leyden jar, L, was arranged in such a manner that, while it received a steady charge from



INDUCTION EFFECT OF LEYDEN JAR DISCHARGE.

M Electrical Machine
L Leyden Jar.
A B Air Spaces between Brass Knobs.
C Conducting Wire.

an electrical machine, it discharged itself, at intervals, across the air space at A, between two brass balls. The discharge had then two alternative paths before it; one through a conducting wire, C, the other across a second air space, between two brass balls at B. During the experiment, the two balls at A were kept at a fixed distance of one inch apart; but the distance between the two balls at B was varied. The conductor, C, used in the first instance, was a stout copper wire, about forty feet long, and having a resistance of only one-fortieth of an ohm.

It was found that, so long as the distance between the B knobs was less than 1.43 inches, all the discharges passed across between the knobs, in the form of a spark. When the distance exceeded 1.43 inches, all the discharges passed through the conductor, C, and no spark appeared between the balls at B. And when the distance was exactly 1.43 inches, the discharge sometimes took place between the knobs, and sometimes followed the conductor, C. The interpretation given to these facts is that the obstruction offered by the conductor C was about equal to the resistance of 1.43 inches of air; and it is proposed to call this distance, under the conditions of the experiment, the *critical distance.*

Coming now to the application of these results, Professor Lodge argues that the conductor C, in his experiment, represents a lightning rod of unimpeachable excellence; and yet, in certain cases, the discharge refuses to follow the conductor, and prefers to leap across a considerable space of air, notwithstanding the enormous resistance it there encounters. In like manner, he says, a flash of lightning may, in certain cases, leave a lightning rod fitted up in the most orthodox manner, and force its way to earth through resisting masses of mason work and such chance conductors as may come across its path.

This conclusion, he admits, is altogether at variance with the received views on the subject; but he contends that it is perfectly in accord with the scientific theory of an electrical discharge. The moment the discharge begins to pass in the conductor, it encounters the obstruction due to self-induction; and this obstruction is so great that the bad conductors offer, on the whole, an easier path to earth.

Variation of the Experiment.—When the experiment was varied by substituting a thin iron wire for the stout copper wire at first employed, a very curious result was obtained. The wire chosen was of the same length as the copper, but had a resistance about 1,300 times as great; its resistance being, in fact, 33.3 ohms. Nevertheless, in this experiment, when the B knobs were at a distance of 1.43 inches, no spark passed, which showed that the discharge always followed the line of the conductor, and therefore that the conductor offered less obstruction than 1.43 inches of air. The knobs were then brought gradually nearer and nearer; and it was not until the distance was considerably reduced that the sparks began to pass between them. When the distance was exactly 1.03 inches, the discharge sometimes passed between the knobs, and sometimes through the conductor; this was, therefore, the *critical distance*, in the case of the iron wire. Thus it appeared that the obstruction offered to the discharge by the iron wire was much less than that offered by the copper, the one being equal to a resistance of only 1.03 inches of air, the other to a resistance of 1.43 inches.

It does not appear that Professor Lodge undertakes to offer any satisfactory explanation of this result. He has come to the conclusion, from his various experiments, that, in the case of a sudden discharge, difference of conducting power between fairly good conductors is a matter of practically no account; and that difference of sectional area is a matter of only trifling account. But he does not see why a thin iron wire should have a *smaller* impedance than a much thicker wire of copper. He proposes to repeat the experiments so as to confirm or to modify the result, which for the present seems to him anomalous.[1]

The Outer Shell only of a Lightning Rod Acts as a Conductor.—As a consequence of self-induction or electrical inertia, Professor Lodge contends that a lightning discharge in a conductor consists of a series of oscillations. These oscillations follow one an-another with extraordinary rapidity—there may be a hundred thousand in a second, there may be a million. Now it has been shown that, when a current starts in a conductor, it does not start at once all through its section; it begins on the outside, and then gradually, but rapidly, penetrates to the interior. From this he infers that the extremely rapid oscillations of a lightning discharge have not time to penetrate to the interior of a conductor. The electricity keeps surging to and fro in the superficial layer or outer shell, while the interior substance of the rod remains inert and takes no part in the action. A conductor, therefore, will be most efficient for carrying off a flash of lightning if it present the greatest possible amount of surface; a thin, flat tape will be more efficient than a rod of the same mass; and a number of detached wires more efficient than a solid cylinder. As for existing lightning conductors, the greater part of their mass would, in many cases, have no efficacy whatever in carrying off a flash of lightning.

The Discussion.—The discussion at the meeting of the British Association was opened by Mr. William H. Preece, F.R.S., Electrician to the Post Office, who claimed to have 500,000 lightning conductors under his control. He expressed his conviction that a lightning rod, properly erected and duly maintained, was a perfect protection against injury from lightning; and in support of this conviction he urged very strongly the report of the Lightning Rod Conference. This report represented the mature judgment of the most eminent scientific men, who had devoted years to the study of the question; and he wished particularly to bring before the meeting their clear and decisive assertion—an assertion he was there to defend—that "there is no authentic case on record where a properly constructed conductor failed to do its duty."

The new views put forward by Professor Lodge were based, in great measure, on his theory that a lightning discharge consisted of a series of rapid oscillations. But this theory should be received with great caution. It seemed to be nothing more than a deduction from

[1] See paper read at the meeting of the British Association, in Bath, 1888, published in the *Electrician*, page 607. September 14.

certain mathematical formulas, and was not supported by any solid basis of observation or experiment. Besides, there were many facts against it. They all knew that a flash of lightning magnetized steel bars, deranged the compasses of ships at sea, and transmitted signals on telegraph wires. But such effects could not be produced by a series of oscillations, which, being equal and opposite, would neutralize each other. It was alleged that these rapid oscillations occurred in the discharge of a Leyden jar. That might be true, and probably was true ; but they were not dealing with Leyden jars, they were dealing with flashes of lightning. If there was any analogy between the discharge of a Leyden jar and a flash of lightning, it was to be found, not in the external discharge employed by Professor Lodge in his experiments, but in the bursting of the glass cylinder between the two coatings of the jar.

Lord Rayleigh thought the experiments of Professor Lodge were likely to have important practical applications to lightning conductors. But though these experiments were valuable as suggestions, they did not furnish a sufficient ground for adopting any new system of protection. It was only by experience with lightning conductors themselves that the question could be finally settled.

Sir William Thomson hoped for great fruit from the further investigation of self-induction in the case of sudden electrical discharges. He warmly encouraged Professor Lodge to continue his researches ; but he expressed no decided opinion on the question at issue. Incidentally he observed that the best security for a gun-powder magazine was an iron house ; no lightning conductor at all, but an iron roof, iron walls, and an iron floor. Wooden boards should, of course, be placed over the floor to prevent the danger of sparks from people walking on sheet-iron. This iron magazine might be placed on a dry granite rock, or on wet ground ; it might even be placed on a foundation under water ; it might be placed anywhere they pleased ; no matter what the surroundings were, the interior would be safe. He thought that was an important practical conclusion which might safely be drawn from the consideration of these electrical oscillations and the experiments regarding them.

Professor Rowland, of the Johns Hopkins University, America, said that the question seemed to be whether the experiment of Professor Lodge actually represented the case of lightning. He was very much disposed to think it did not. In the experiment almost the whole circuit consisted of good conductors ; whereas, in the case of lightning, the path of the discharge was, for the most part, through the air, and therefore it might be an entirely different phenomenon. The air being a very bad conductor, a flash of lightning might, perhaps, not consist of oscillations, but rather of a single swing. Moreover, it was not at all clear that the length of the spark, in the experiment, could be taken as a measure of the obstruction offered by the conductor. Professor George Forbes was greatly impressed with the beauty and significance of Professor Lodge's experiments, but he did not think the result so clear that they should be warranted in abandoning the principles laid down by the Lightning Rod Conference.

M. de Fonvielle, of Paris, supported the views of Mr. Preece. He cited the example of Paris, where they had erected a sufficient number of lightning conductors, according to the received principles, and calamities from lightning were practically unknown. He suggested that the Eiffel Tower, which they were now building, and which would be raised to the height of a thousand feet, would furnish an unrivalled opportunity for experiments on lightning conductors.

Sir James Douglass, Chief Engineer to the Corporation of Trinity House, had a large experience with lighthouse towers. The lightning rods on these towers had been erected and maintained during the last fifty years entirely according to the advice of Faraday. They never had a serious accident; and such minor accidents as did occur from time to time were always traced to some defect in the conductor. They had now established a more rigid system of inspection, and he, for one, should feel perfectly safe in any tower where this system was carried out.

Mr. Symons, F.R.S., Secretary to the Meteorological Society, had taken part in a discussion on lightning conductors as long ago as 1859. It had been a hobby with him all his life to investigate the circumstances of every case he came across in which damage was done by lightning, and the general impression left by his investigations entirely coincided with the views just expressed by Sir James Douglass. He had been a member of the Lightning Rod Conference, and was the editor of their report; and he wished to enter his protest against the idea of rejecting all that had hitherto been done in connection with lightning conductors on the strength of mere laboratory experiments.

Professor Lodge, in reply, said he could perfectly understand the position of those who held that a lightning rod properly fitted up never failed to do its duty, because, whenever it failed, they said it was not properly fitted up. The great resource in such cases was to ascribe the failure to bad earth contact. He thought a good earth contact was a very good thing, but he could not understand why such extraordinary importance should be attached to it. A lightning rod had two ends—an earth end and a sky end—and he did not see why good contact was more necessary at one end than at the other. If a few sharp points sticking out from the conductor were sufficient for a good sky contact, why were they not sufficient also for a good earth contact?

Besides, though a bad earth contact might explain why a certain amount of disruption should take place at the earth where the bad contact existed, he did not see how it accounted for the flash shooting off sideways half-way down the conductor. Again, what does a bad earth contact mean? If an electrical engineer finds a resistance of a hundred ohms, he will rightly pronounce the earth contact to be very bad indeed. But why should the lightning flash leave a conductor with a resistance of a hundred ohms in order to follow a line of non-conductors where it encounters a resistance of many thousand ohms?

He accepted the statement of Mr. Preece that his whole theory depended on the existence of oscillations in the lightning discharge; but there was good reason to believe they existed, because they were proved to exist in the discharge of a Leyden jar. Mr. Preece objected that an oscillating discharge could not produce magnetic effects, as a flash of lightning was known to do. He confessed he was unable to explain how an oscillating discharge produced such effects;[1] but that it could produce them there was no doubt whatever, for the discharge of a Leyden jar produces magnetic effects, and we have ocular demonstration that the discharge of a Leyden jar is an oscillating discharge.

As to the assurances we had received from electrical engineers that a properly fitted lightning conductor never fails, he should like to ask them how the Hotel de Ville, in Brussels, had been set on fire by lightning on the 1st of last June. The system of lightning conductors on this building had been erected in accordance with the received theory, and had been held up by writers on the subject as the most perfect in Europe. Unless some explanation were forthcoming to account for its failure, we could no longer regard lightning conductors as a perfect security against danger.

The President of Section A, Professor Fitzgerald, in bringing the discussion to a close, observed that one result of this meeting would be to give a new interest to the phenomena of static electricity and its practical applications. He was inclined himself to think that the experiments of Professor Lodge were not quite analogous to the case of a flash of lightning. In comparing the discharge of a Leyden jar with a flash of lightning they should look for the analogy, not so much in the external discharge through a series of conductors, but rather, as Mr. Preece had observed, in the bursting of the glass between the two coatings of the jar. As regarded the oscillations in a Leyden jar discharge, he did not think such oscillations were at all necessary to account for the phenomena observed in the experiments. Many of the results which Professor Lodge seemed to think would require some millions of oscillations per second would be produced by a single discharge lasting for a millionth of a second. Improvements, perhaps, were possible in our present system of lightning conductors,

[1] See a very ingenious hypothesis, to account for this phenomenon, suggested by Professor Ewing in the *Electrician*, p. 712. October 5, 1888.

but practical experience nad shown, however we might reason on the matter, that, on the whole, lightning conductors had been a great protection to mankind from the dangers of lightning.

Summary.—I will now try to sum up the results of this interesting discussion, and state briefly the conclusions which, as it seems to me, may be deduced from it. First, I would remind my readers that a lightning rod has two functions to fulfill. Its first function is to promote a gradual, but rapid, discharge of electricity according as it is developed, and thus to prevent such an accumulation as would lead to a flash of lightning. Its second function is to convey the flash of lightning, when it does come, harmless to the earth. Now, the new views advanced by Professor Lodge in no way impugn the efficiency of lightning rods as regards their first function ; and it is evident that the greater the number of lightning rods distributed over a given area, the more perfectly will this function be fulfilled. This is a point of great practical importance which seemed to me, in some degree, lost sight of during the progress of the discussion.

Secondly, it was practically admitted by the highest authorities that the experiments and reasoning of Professor Lodge afford good grounds for reconsidering the received theory of lightning conductors as regards their second function—that of carrying the lightning flash harmless to the earth. But there was undoubtedly a general feeling that it would be rash to set aside, all at once, the received theory on the strength of laboratory experiments made under conditions widely different from those which actually exist in a lightning discharge. Experiments are wanted on a larger scale ; and, if possible, experiments with lightning rods themselves.

Thirdly, the testimony of electrical engineers who have had large experience with lightning conductors seems almost unanimous that a lightning conductor erected and maintained in accordance with the conditions prescribed by the Lightning Rod Conference gives perfect protection. It was certainly unfortunate that the Hotel de Ville, in Brussels, which was reputed the best protected building in Europe, should have been damaged by lightning just two months before the discussion took place ; but no certain conclusion can be drawn from this catastrophe until we know exactly the conditions under which it occurred.

So the matter stands, awaiting further investigation.

Beacon Lights of Science

ELECTRICITY

E. M. CAILLARD

PREFACE.

The aim which the writer has proposed to herself in the present little work, is to give such an outline of modern electrical science as may be readily understood by readers who have no previous acquaintance with the subject, and who, though unable to make a serious study of it, wish to acquire sufficient knowledge to enable them to follow with intelligent interest the marvelous and rapid progress which is being made in this ever-widening field. That a science so comprehensive as that of electricity should be exhaustively dealt with in a sketch for general readers, is out of the question, even though the task had fallen to a far more competent pen than that of the writer. Nevertheless, a sketch sometimes answers a very useful purpose, in awakening a keen desire for a closer and fuller acquaintance with the truths of which it gives an indication. Should this be the case in the presence instance, the writer would be abundantly rewarded for what has been throughout a labour of love. At any rate most persons will agree with her, that to have no knowledge whatever of the striking advances which are being made in all branches of physical science, and especially in those which fall within the scope of "Electricity," is a considerable intellectual loss. It is even more than this, for there is no aid to faith in the Invisible greater than the pursuit of knowledge, which is for ever obliged to penetrate beyond the apparent in order to keep in touch with the real.

In conlusion, the writer desires to express the deep obligation under which she lies to Professor Ayrton, for most valuable assistance in the revision of the proofs, without which she feels that her work would have far less right to be regarded with confidence than she trusts is now the case. She has also to acknowledge the courtesy of Professor Silvanus Thompson and his publishers, in allowing her the use of several illustrations (Figs. 11, 12, 13 and 14) from his work, "Elementary Lessons in Electricity and Magnetism;" and of Messrs. Siemens Brothers; Lang, Wharton and Down; and Batley and Greenwood, for the illustrations of dynamos, etc., in Part IV.

EMMA MARIE CAILLARD.

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STATIC ELECTRICITY

OR

ELECTRICITY AT REST

PART I.

CHAPTER I.

ELEMENTARY PHENOMENA.

Definition of Static Electricity—Electrical attraction—Known to the ancients as a property of amber—Gilbert's discoveries—Electrical repulsion—Two opposite states of electrification—Explanation of the terms vitreous and resinous—Superseded by positive and negative—Franklin's theory—Idea of excess and defect acknowledged in modern science—Proofs of its correctness—Analogy between the present state of knowledge of positive and negative electricity and the prescientific knowledge of heat and cold—Conductors and non-conductors—Meaning of charge and discharge—Induction—Action of points.

UNDER the head of *Static Electricity* are classed those phenomena which are not caused by a continuous flow or "current" of electricity; and though they were the earliest known, and are frequently considered as appertaining more or less to elementary knowledge, they yield neither in interest nor importance to the other branches of the science. Of late, special attention has been devoted to them by various scientific experimenters, as modern research leads to the opinion that here, if anywhere, will be found the ultimate solution of some of the many vexed questions surrounding that ever-recurring inquiry, "What is electricity?" Moreover, the eminently practical and useful study of atmospheric electricity belongs chiefly to this branch of the science, which cannot therefore be considered as either barren or uninteresting.

The first electrical phenomenon which claims our attention is that of attraction. Through the whole domain of Nature we are familiar with attraction under one form or another. There is the attraction of the members of the solar system for each other and for their great centre; the attraction between the earth and all terrestrial objects; the attraction between particles (or molecules) of matter, which enables them to form into the larger and smaller masses which we call bodies; lastly, there is the attraction between the elementary chemical atoms leading them to combine and re-combine in an endless variety of ways, thus producing all the different substances with which we are acquainted. And now on the threshold of this latest developed science we are confronted with the phenomenon of attraction again, in a new form and under different conditions certainly, but an old friend nevertheless.

It is supposed that Thales, one of the seven sages of Greece, was the first to discover that amber when rubbed acquired the power of attracting small light bodies to itself. Be this as it may, the fact was known to his countrymen hundreds of years before the Christian era; and to the Greek word "electron," amber, is due the name electricity.

Two thousand years passed away, and, save that jet was found to share the same property as amber, no further advance was made in electrical knowledge. Then, in the reign of Elizabeth, so fruitful in progress of all descriptions, Dr. Gilbert, of Colchester, whom the Queen had appointed her physician chiefly out of admiration for his acquirements in natural science, added several facts to the one which had so long held the field alone. He found that glass, rock-crystal, gems, sulphur, resin, and various other substances developed on friction the same power of attraction as amber and jet. He called these electrics. Metals and such substances as appeared devoid of any attractive property he termed non-electrics. Gilbert was wrong in this classification, however; for, under suitable conditions, to be presently described, all substances behave as electrics. Gilbert also ascertained that moisture prevented the success of his experiments, and that an electrified body, if set on fire, passed through a flame, or made very hot, lost all sign of electricity.

It is easy to reproduce Gilbert's experiments on electrical attraction. A rod or tube of glass held in the hand and rubbed with a silk cloth will powerfully attract small pieces of paper, pith, or other light bodies, just as a magnet will attract steel filings or needles; with the difference, however, that whereas in the magnet the force of attraction seems to lie in the two ends, in the rubbed glass it exists all over the surface, so that the pieces of paper will adhere to it anywhere.

Electrified objects possess a force of repulsion as well as of attraction; for, in making the above experiment, it will be noticed that in a very short time the pieces of paper or pith fall off the glass, and will not at once be attracted to it again. If, however, while they are in a state of repulsion toward the glass, a stick of rubbed sealing-wax be approached, they immediately fly toward and adhere to that, to be again soon repelled, when the glass will be once more found able to attract them. These phenomena point to the conclusion that bodies can be electrified in two ways, and that those electrified in the same way repel, while those electrified in opposite ways attract each other.[1] A still more striking proof is afforded by the fact that a couple of rubbed glass rods suspended by silk threads repel each other, and so do two rubbed sticks of sealing-wax, but the glass attracts the sealing-wax and the sealing-wax the glass.

These opposite kinds of electricity were at first called *vitreous* and *resinous*, because it was believed that "vitreous" substances always gave signs of one kind of electricity and "resinous" of the other. This is a mistake, however. Glass rubbed with silk becomes "vitreously" electrified, but rubbed by fur becomes "resinously" electrified. It is evident, therefore, that the kind of electricity manifested depends on some relationship between the rubber and the object rubbed; and it is now supposed that the substance whose molecules are least disturbed by friction shows "vitreous" electricity, and the one where they are most disturbed "resinous." These terms vitreous and resinous have, however, quite fallen into disuse, and are replaced by *positive* and *negative*, known in technical works by the signs + and —. The American philosopher, Franklin, was the first to introduce them, as he was also the first to formulate a theory justifying their use. He supposed that electricity was an invisible and imponderable fluid, existing in a certain fixed quantity in all bodies in a natural state, and that the positive state of electrification showed an excess, and the negative state a defect of this fluid. Whether electricity be or be not a fluid,[2] it is now agreed that it is equally distributed in all bodies which are in a natural state, and that the idea of excess and defect does truly represent the conditions that occur in positive and negative electrification; which is actually the state of excess and which of defect not being, however, a matter of certainty. Practically, positively electrified bodies are considered and treated as those in which there is an excess of electricity.

[1] It has been proved that two small electrified bodies attract or repel each other with a force varying inversely as the square of the distance between them. This law is known as Coulomb's law, he having been the first to discover it.

[2] It is certainly not a fluid in the ordinary acceptation of the term; and in speaking of electricity at all as a separate entity, care must be taken to remember that this is done for convenience' sake. We speak of "electricity" as we might speak of a gale or a whirlwind. These have no existence apart from the air of which they are certain states or conditions, and in the same way the various electrical phenomena are caused by conditions not of the air, but of another medium, to which further reference will be made hereafter.

One proof of the truth of this theory of excess and defect lies in the fact that it is impossible to produce a manifestation of one kind of electricity without causing an equal quantity of the other to appear also. A rubbed glass rod becomes positively electrified, but the silk which rubs it becomes negatively electrified, as can be seen by using it fastened to a glass handle instead of holding it in the fingers. After friction it will be found that both the glass rod and the silk will attract small neutral bodies, and that when these are respectively repelled, those repelled by the glass will be attracted by the silk and *vice versa.*

Many persons seem to find a difficulty in these terms positive and negative, asserting that it is impossible to attach a definite meaning to them, as they convey no clear idea to the mind. There is no doubt, indeed, that if scientific men really knew what positive and negative electricity are they would be able to find better names for them. In the meanwhile, as the idea which is wanted to be conveyed is that the two electricities are of opposite kinds, perhaps the terms positive and negative are as good as any that could be put forward. One is almost afraid in the present state of knowledge of venturing the analogy, but possibly the experience which has been gone through in the case of heat and cold may aid the conception of some readers. Cold is the opposite of heat; we now know that it is merely a negation, the absence of heat; people did not always know this. They supposed that cold was a thing in itself, but this error did not prevent their having a very clear practical conception of what cold was, and of knowing what they must do to neutralize it—produce heat. In the case of electricity the converse of this experience is taking place. We say positive and negative electricity are opposite, and it has been assumed that the positive is the thing in itself, and the negative, the negation, the want of this thing. But this is not true; negative electricity is as real as positive, though no one can pronounce what either is. Pending further discoveries, however, we may have, and electricians have, quite as good a working conception of positive and negative electricity as the generality of mankind had of heat and cold before science had discovered what these really were. Moreover, it is perfectly understood what must be done to neutralize one kind of electricity—produce the other.

It will have been observed that a silk thread was recommended for suspending the glass and sealing-wax in one of the experiments above described, and that in order to discover the electrical state of the rubber it must not be handled in use, but fixed to a glass stem. The reason is that some substances are conductors, and some non-conductors of electricity. An electrified body placed in contact with the former at once parts with its surplus electricity to them, or, if it be in a state of defect, receives from them the electricity needful to restore it to a natural state. Non-conductors, on the contrary, do not allow of the free passage of electricity to and from them in this way, and consequently an electrified body, in contact with them only, cannot return to its normal condition until it has been touched by a conductor. To this latter class belong all metals, impure water and charcoal. Animal bodies, dry wood, and a few other substances are partial conductors. Oils, silk, porcelain, dry air, and all the so-called "electrics" are non-conductors or *insulators*, thus named because an electrified body surrounded by them is insulated, so far as its electrical condition can be affected by conduction, from every other object; and any body, no matter how good a conductor it may be, will in such a position become an "electric." It is for this reason that Gilbert's division of bodies into "electrics" and "non-electrics" was erroneous. Had he fastened a piece of metal to a clean, dry glass support, and touched it with an electrified body, he would have found the metal acquire the same property of attraction as amber or rock-crystal; for conductors need nothing more than contact at one point with electrified bodies to become electrified themselves over their whole surface. In the case of non-conductors, on the contrary, every part of the surface must be separately touched and excited. It is for this reason that friction is necessary in their case, and it will be the more effectual the more markedly different is the electricity which they develop; for there are stages in this respect, some substances being relatively to each other much more decidedly positive and much more decidedly negative than others.

A body in an electrified state is said to be "charged," and it is "discharged" when it returns to its natural condition. At the moment of discharge a crackling noise is often heard, and, if in the dark, small sparks may be seen. The rubbing of a cat's back with the hand will produce these, and also, in certain dry states of the atmosphere, combing the hair. Conductors are instantaneously discharged if touched by the hand, or by any object in connection with the earth (*i. e.*, in electrical connection by conductors, or partial conductors, such as the floor and walls of a house, for instance); but in the case of a "highly" charged body, it is not always safe to use the hand as a discharger, for the passage of electricity through a living body produces curious and strongly marked physiological effects, and in some instances the disturbance may be so great as to occasion loss of consciousness, and even of life, as when a person is "struck" by lightning. It is hardly necessary to observe, however, that to produce such phenomena as these an apparatus very different from rods of glass and sealing-wax is required; and, in fact, for any but the most elementary experiments an electrical machine is needed. Before entering into any details on this subject, however, some description must be given of what is called *electrical induction*.

An electrified body brought near a conductor has the power of causing the latter to become electrified also, but in the opposite way to itself. Thus, if the former be positively charged, the latter will become negatively charged ; and although, if uninsulated, it would be incapable under ordinary circumstances of retaining the electrified state, in the present instance it will do so, as long as it remains in the neighborhood of the influencing conductor. Such a charge as this is called an *induced charge*, and electricity under such conditions is said to be *bound*, because the close proximity of a charge of the opposite nature prevents it from availing itself of the open way of escape to the earth, which it would otherwise immediately take. If both the conductors are insulated, the effect produced is different. Suppose the inducing charge to be positive as before, it cannot now give rise to an induced charge which is wholly negative, because there is no means of escape for the positive electricity contained in the conductor which is being influenced. The negative electricity of the latter is therefore attracted to the end nearest the positively charged conductor, and the positive electricity is repelled to the farther end, so that the two ends are electrified in opposite ways, while the middle appears to be in its normal condition (see Fig. 1). Could the conductor be divided in two—an arrangement often made to exhibit this phenomenon—that half of it which had been nearest the positively electrified body would be found negatively charged, and that which had been farthest from it, positively charged. Charge by induction differs from that by conduction, therefore, in the fact that the former can be caused by altering the distribution of electricity, while the latter requires an alteration of quantity. For instance, if an uncharged insulated conductor were brought near a positively charged insulated body (as in Fig. 1), no electricity would be put into or taken out of the former ; so that if its power of acquiring a charge depended only on an alteration of the quantity of electricity possessed by it, it could not under these circumstances be charged at all. Yet, as a fact, a conductor thus placed does become charged, one end (or side, if it be an upright bar or sheet of metal) positively, and the other negatively. If the influencing body be taken away, the conductor will return to its natural electrical state ; but if the former be left, and the latter connected to earth, the conductor will become, as we have seen, negatively charged ; and if it be then insulated again, and the positively charged body removed, it

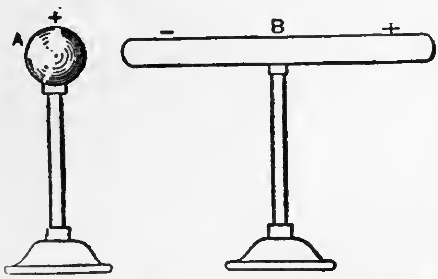

FIG. 1.—Diagram illustrating the charge induced in an insulated conductor B, by the neighborhood of a positively electrified body A.

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will retain its negative charge, because now an alteration has taken place in the quantity of electricity it possesses, some having escaped to the earth, and therefore while insulated it cannot return to its natural condition.

We have hitherto been considering the inducing and induced charges as separated by a thickness of air great enough to form an insurmountable barrier to their union. Suppose the two bodies to be approached nearer to each other, this barrier may become too slight to resist the strain which is going on ; and, just as the pressure of water on a dam may burst the dam, so the accumulated electric pressure bursts the insulating medium, a spark and report take place, and the two bodies are discharged. The subject of induced charges and the phenomena connected with them is full of interest, and will be referred to at greater length in Chapter IV. Meanwhile, before entering on a description of electrical machines, another fact of great importance must be stated, viz., the action of points on electricity. Franklin was the first to discover this, and he found that their effect is twofold. A pointed conductor both collects a far greater quantity of electricity than one with a flat or rounded surface, and the discharge from it is also much more rapid and powerful.

CHAPTER II.

ELECTRICAL MACHINES AND THEIR EFFECTS.

General principles of electrical machines—Von Guericke's machine—Cylinder and plate machines—Use of points in electrical machines—Experiments with electrical machines—Electric chimes—Electric windmill—Luminous effects—Electric spark—Brush discharge—St. Elmo's fire—Electrical glow—Discharge through rarefied air and gases—Return shock—Production of ozone—Difference between frictional and influence machines—The electrophorus.

AN electrical machine must always consist of two principal parts, one for producing and the other for collecting electricity ; and in *frictional machines* the quantity of electricity brought into play depends on three things—the extent of surface subjected to friction, the amount of friction used, and the nature of the two substances brought into contact. These should always be chosen so that the one should be the most positive and the other the most negative possible, relatively to each other. The first frictional machine was invented by a German, Otto von Guericke, in 1680, and consisted of a large sulphur ball, supplied with a wooden axle, and mounted on a frame. The hand was used as a rubber ; and with this simple contrivance

Von Guericke succeeded in producing much more powerful effects than had ever been obtained before.

The modern frictional machine is, however, very far superior to this. The surface to be rubbed usually consists of a large glass cylinder or plate, provided with a handle by which it can be turned, and the rubber of a leather cushion or cushions, coated with a powdered amalgam of zinc or tin. In front of the glass, but not touching it, is placed the "prime conductor," which must, of course, be insulated. It consists in the case of the "cylinder machine" (Fig. 2) of a thick bar of metal, either solid or hollow, placed on glass supports, and provided with a row of small metal spikes at the end nearest the glass cylinder; and in the case of the plate machine, of two bars similarly armed, or of one bent round so that both its ends should be presented to the flat surface of the glass, or else of a large metallic ball, on which a smaller one is often placed. When the handle is turned, positive electricity appears on the glass and negative on the rubbers, which are generally provided with a metal chain, con-

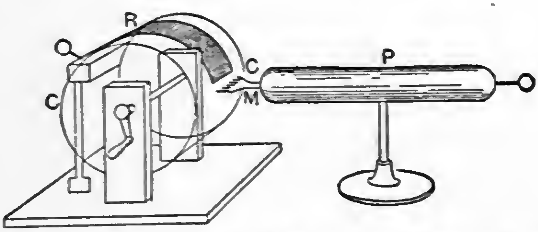

Fig. 2—Cylinder Frictional Machine. C C, glass cylinder; R, rubber; P, prime conductor; M, metal comb.

necting them to "earth" through the floor and walls of the building. The positive charge on the glass induces a negative charge on the nearest end of the prime conductor, whose positive electricity is repelled to the farther end, and is in fact the charge used for the experiments required. The metal points discharge the negative electricity at the near end, in a powerful stream, on that part of the glass plate which is opposite to them for the moment, and which consequently returns to the rubbers as the plate continues to revolve, unelectrified and ready to be excited again. This is an important part of the arrangement, because bodies cannot receive an unlimited amount of electricity. When charged up to a certain degree (which varies according to the shape, size, and position of the body), they cannot be further electrified until discharge has taken place; and the glass plate of the frictional machine would reach its highest effective point, and be incapable of further strengthening the induced charge on the prime conductor, in a very short time, if it were not for the action of the points above described. As the machine is provided with these, however, the induced positive charge at the far end of the conductor becomes very powerful, and long sparks can be drawn from it by presenting another conductor, and experiments performed to demonstrate various electrical phenomena. One sometimes made use of to illustrate attraction and repulsion is the production of "electric chimes," first invented by Franklin. Three bells are hung from the prime conductor, the two outer ones by wires, the inner one by a silk thread, and having attached to it a metal chain connected with the ground. Two brass balls hung by silk strings are placed between the bells, which being positively electrified through their connection with the prime conductor, attract them, and are struck by the balls. The latter becoming immediately charged with the same electricity, are repelled and attracted toward the uninsulated central bell, against which they strike and discharge themselves, when the outer bells again attract them. Thus they go on alternately charging and discharging themselves, and causing thereby the musical "electric chimes."

Another experiment often shown is the electric windmill, which illustrates the action of points. It consists of straws or very light metal wires placed crossways and supported on a pivot, with the pointed ends all bent at right angles in the same direction. The whole arrangement is then fixed on the prime conductor of an electrical machine, and becomes strongly electrified, the greatest quantity of electricity collecting at the points, from which it streams off, causing, by the repulsion of the air-particles which it electrifies, a current of air known as an electrical "whirl." The effect of this is to drive the windmill rapidly round in the opposite direction to that of the points. Such a current is often strong enough to blow out the flame of a candle, and can always be felt by placing the hand in its path.

Beside demonstrating very strikingly electric attraction and repulsion, the action of points, and various other interesting phenomena, electrical machines can also produce luminous effects, which are simply reproductions on a small scale of the grand and beautiful natural appearances caused equally by electricity. The electric spark has already been mentioned, and it is simply a miniature flash of lightning; the very shape of the one, with its sinuous and branching appearance, irresistibly recalling the other, even to the most cursory observation. The electric spark is vivid enough to be seen in broad daylight, but an equally beautiful though less brilliant effect is the brush discharge, which requires a darkened room in order to be made visible. It is caused by a continuous flow of electricity from some conducting body. To facilitate this from an electrical machine, a piece of wire filed at one end is attached to the prime conductor, or, if the latter be highly charged, a bullet will answer the purpose. A fan-like brush of light, whose pointed end rests on the piece of wire or bullet, is then seen, varying in strength according to the nature and amount of charge of the conductor, and being always larger and brighter when the latter is positively than when it is negatively charged. The brush discharge is usually accompanied by a continuous hissing noise, very different from the sharp crack of the spark; but if the conductor be pointed the discharge takes place silently, and is attended by a pale-blue light, called an "electrical glow," which becomes a small bright star if occasioned by negative electricity. "St. Elmo's fire," often seen by sailors on the masts of their ships, is an example of glow discharge. It is also sometimes observed on trees, and more frequently on spears and lanceheads, or on the points of bayonets. Such appearances only occur when the atmospheric electricity is in a very disturbed state, most frequently before and during storms.

The usual appearance of the electric spark is, as has already been stated, that of a miniature flash of lightning; but if it is made to pass through a tube in which the air has been rarefied, a great change takes place. The light assumes a violet tint, and spreads out so as to fill the whole tube, if the latter be not too wide, flickering in such a way as to suggest the idea of undulations traveling in the same direction as the positive electricity. "Geissler's tubes" are generally used for making experiments of this kind. They are simply thin glass tubes, blown into the required shapes and partially exhausted of air; into each end is fused a piece of platinum wire, by means of which the spark is conducted into the tube. Very interesting and beautiful effects are produced by these means. It is found that at the positive pole there is usually a single small bright star of light, while the negative pole is surrounded by a blue or violet-tinted glow, separated from the pole, however, by a small dark space. The more the air is rarefied the paler does the luminous discharge become, and if exhaustion is carried to a sufficiently high pitch the whole tube becomes dark. The darkness appears to proceed from the negative pole, as with every increasing stage of exhaustion the dark space between it and the glow of light grows wider. Sometimes all the light in the tube breaks up into successive patches or *striæ*, as they are called, which vibrate to and fro. These striæ have their origin at the positive pole, and commence at a certain pitch of exhaustion, increasing in number as this increases for some time, when if the air or gas be still further rarefied they grow fewer and thicker. The color of this luminous discharge is found to vary with the kind of gas through which it passes, and also with the nature of the metallic conductors forming the opposite poles. The former cause is most active when the discharge is weak, and the latter when it is powerful. To observe the color it is best to use narrow tubes. The light is seen to be of a violet tint in air and oxygen, blue in nitrogen, red in hydrogen, and white in carbonic acid.[1]

The effect produced by the metal conductors on the color of the luminous discharge seems to be due to the vaporization of small particles, owing to the intense heat developed at the respective poles, and, indeed, along the whole passage of the spark. This heat is so great that fine wires may be made red hot and even fused by it, presenting an analogy to what sometimes occurs in the case of lightning and lightning conductors. The latter, especially in former days, when their proper construction was less well understood, have not infrequently been melted by a violent discharge.

Persons standing near a powerful electrical machine at work often experience a curious sensation, as though a cobweb were spread over the face, and when it is discharged they perhaps feel a "shock;" this is the same thing as what is known as the "return shock" in the case of a lightning flash, and is caused by induction.[2] In both cases the presence of a charged body (be it cloud or electrical machine) causes a charge of opposite sign in other bodies near it, and when it is discharged they also discharge themselves, and in the case of a living being a "shock" is felt. There is also invariably a peculiar and powerful odor in the neighborhood of an electrical machine in action, due to the presence in large quantities of ozone, which is a modified and, so to speak, condensed form of oxygen, and to which further reference will be made in a future chapter.

The machines of which a slight description has been given above, though partly owing their efficiency to induction, are known by the name of frictional machines, since it is friction which generates and keeps up the supply of electricity. There are, however, other machines much more powerful, and greatly used in laboratory experiments, which are wholly dependent on induction; and just as the parent of the perfected frictional machines of modern days was the homely apparatus of Otto von Guericke, so the progenitor of the powerful "influence" machines is the simple, and, to all students of electricity, familiar little instrument known as the *electrophorus*.

As its name indicates, it is a contrivance for carrying electrical charges from one place to another. It consists of three parts, two metal discs or plates, one of which is provided with a glass handle, and a slab of resin or ebonite—usually the latter in modern instruments—which fits into the lower plate (see Fig. 3). The ebonite is electrified by friction with wool or fur, its charge being, of course, negative. The upper metal disc is then placed upon it, but does not

[1] Sparks from induction coils are more frequently used in these experiments than those from electrical machines. See p. 97.

[2] It appears, however, that other causes may be at work to produce the return shock. See p. 44, note.

actually touch more than three or four points of the surface, from which it is separated by a very thin film of air, so that it is really in the position of an insulated conductor in the close neighborhood of an electrified body, and becomes positively charged by induction, the negative electricity being repelled to the outer surface. The disc is then touched with the finger, or in some way momentariiy connected to earth (so that the negative electricity escapes), and being lifted away from the ebonite by means of the insulating handle, is found to have retained a positive charge powerful enough to permit a good-sized spark to be drawn from it, if another conductor be presented to its surface. As the disc was electrified by induction, no part of the original charge of the ebonite has been taken away, and the latter will be capable of recharging the disc an indefinite number of times without requiring to be again electrified itself. The simplest way of understanding the action of the

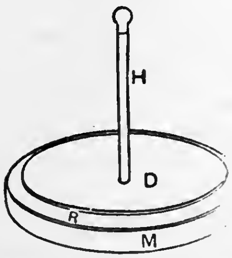

FIG. 3.—Electrophorus. M, lower metal plate; R, resin or ebonite disc: D, upper metal plate attached to H, insulating handle.

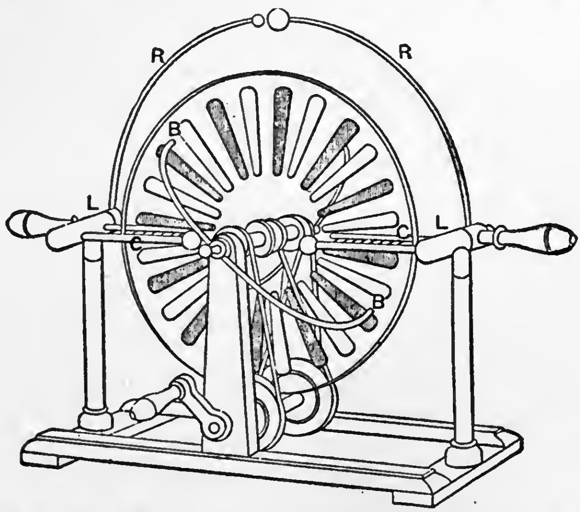

FIG. 4.—Wimshurst Influence Machine. This machine consists of two circular glass plates, about 1/8 of an inch apart, and made to revolve in opposite directions when the machine is at work. Each of these glass plates has attached to the outside a number of metallic sectors arranged like the spokes of a wheel. These sectors perform the office of both inductors and carriers, the carriers on one plate acting as inductors to the carriers on the opposite plate. The machine is provided with two discharging rods R R (whose knobs must be separated, and the rods themselves connected to the insulated brass cylinders L L, when the machine is to be used for charging any body), four collecting combs (two of which, C C, are seen in the figure), and two curved brass rods B B (one only represented), which carry at their ends small wire brushes connecting the pair of carriers which are at the moment under the influence of the inductors.

electrophorus is to bear in mind that when the ebonite has received its negative charge, and the metal plate attached to the glass handle is placed upon it, both this plate and the one under the ebonite have positive charges induced on the surfaces facing the ebonite. Therefore, if either plate be connected to earth, and then insulated and removed, it will retain a positive charge (see p. 12). The charge thus communicated to the electrophorus can be conveyed to any conducting body and given up to it by contact, and if the process is repeated often enough an insulated conductor may thus become electrified to a high degree. In an ordinary electrophorus there is no way of giving rise to or increasing the original charge on the ebonite except by friction. In the accumulating influence machines, referred to above, however, which are made on the principle of the electrophorus, the initial charge is produced in quite a different way (explained on page 21), and is increased by a system of action and reaction, which enables influence machines to produce effects far exceeding in magnitude any to be obtained by the same amount of mechanical labor from frictional machines. The best known influence machines are the Holz and the Wimshurst. The latter is represented in Fig. 4, but its principle cannot be understood until the explanation respecting *potential*, and *difference of potential*, given in the ensuing chapter, has been read (p. 21).

CHAPTER III.

ELECTRICAL CHARGES—SOURCES OF ELECTRICITY OTHER THAN FRICTION.

Seat of "charge"—Biot's experiment—Faraday's experiment with conical bag—Proof-plane—Distribution of electricity on the surface of a sphere—On other surfaces—Density—Cause of charge—Analogy with dammed-up water—Importance of insulating medium—Capacity of bodies—Potential—Detection of charges—Gold leaf electroscope—Slightness of causes producing charge—Measurement of charges—Torsion balance—Coulomb's law—Electrometers—Difference between force and quantity—Various sources of electricity—Electricity not made but caused to manifest itself by disturbance of equilibrium—Analogy with air.

HITHERTO nothing has been said as to the seat of the charge in an electrified body, though the expressions used may have led to the true inference that it resides wholly on the surface. The interior of a conductor is never found to be electrified when electricity is at rest on it. The outer surface alone is capable of "charge."

This has been proved in a variety of ways. One experiment known as Biot's[1] is to electrify an insulated metal ball, over which two

[1] It was really first performed by Cavendish.

hemispheres, also made of metal and provided with glass handles, can be fitted. So long as the hemispheres do not touch the ball, it retains its electrified state, but the most momentary contact suffices to transfer the whole charge to the outer surface of the hemispheres, the ball being left without a trace of electricity. Another experiment, devised by Faraday, is to electrify a conical linen bag placed on an insulating stand, and provided with silk strings by which it can be turned inside out. When electrified, the charge is ascertained to be on the outside; the strings are then pulled, so that what was the inner becomes the outer surface, and the charge is again found to be on the outside, showing that the electricity must have passed from one surface to the other in order to retain its outside position.

A third way of proving the same fact is by means of a little instrument called the proof-plane. This is a very small metal disc or bead fastened to a glass stem, and which when placed in contact with an electrified body receives a small part of the charge. If this disc be carefully inserted in a hollow metal ball which has been electrified, and be made to touch the inner surface, no trace of electricity is communicated to it, but it becomes charged directly by momentary contact with the outer surface.

A sphere sufficiently far removed from other conductors to be practically outside the range of their influence, is the only body over whose surface electricity distributes itself with perfect equality. Bodies of any other shape will have more electricity on some parts of their surface than on others, and at every point or edge it will collect in greater quantities than anywhere else. The quantity of electricity per unit of area (*i. e.* per square centimetre), at any given spot on the surface of a body, is called the *density* of electricity at that spot; and wherever the greatest density is, there also will the greatest effort be made to escape, and there will the discharge, if there is one, take place.

The fact that charges reside only on the surface of bodies, points to the conclusion that the real seat of the effects produced is not after all the conductors, as was formerly supposed, but the insulating medium by which they are surrounded. If all bodies were perfectly conducting, there could be no possibility of disturbance in electrical equilibrium, because electricity could pass freely to and from all, thus finding its own equality of distribution, as water finds its own level. A "charge" occurs because at the surface of a conductor the electricity meets with a medium into which it cannot pass, and it as it were piles itself up so as to acquire strength to break through. Dammed-up water and an electric charge are much in the same situation. Both are unnaturally confined, both will escape from confinement if they possibly can; the water either by overflowing or bursting its banks, the electricity also by overflow, *i. e.*, leakage, or by discharge, *i. e.*, by suddenly bursting the imprisoning medium. Faraday was the first to point out that the study of the insulating medium was in fact of far greater importance than that of conductors ; and since his time the attention of electricians has been much more turned in this direction, to the great benefit both of theoretical and practical knowledge.

It is evident that all electric charges cannot be alike ; the same body may receive either a small or a large charge. Again, different bodies have what is called a different *capacity* for charge, *i. e.*, some are capable of accumulating a larger quantity of electricity than others. The capacity of a body depends partly on its size ; the larger it is, *i. e.*, the greater extent of surface it possesses, the greater the quantity of electricity it can receive ; but capacity is also affected by other causes, to be mentioned hereafter.

The electrical condition of a body compared with that of some other body or bodies is called its *potential*, and a charge may be one of either high or low potential. A small body receiving a certain amount of electricity may be at a high potential ; a much larger body receiving the same amount of electricity would be at a low potential ; and the tendency of electricity is always to flow from a body at high potential to one at low potential, so as to equalize its distribution, just as the tendency of water is to flow from a high to a low level for the same reason. In fact, it is often said that potential is to electricity what level is to water ; and as in measuring elevations the sea level is taken as zero, so in measuring differences of potential, or differences in electrical level, the surface of the earth, which is nevertheless always slightly electrified, is arbitrarily taken as zero. Another analogy between level and potential may be permitted. Falling water does work in passing from a higher to a lower level ; electricity in passing from a higher to a lower potential does work also, and in charging a body the same kind of operation is performed as in pumping up water. Work is expended in order that the capability for work may be produced.

The potential of a conductor may be varied in one of three ways : (1) by altering its charge (increasing the charge increases, diminishing the charge diminishes, the potential) ; (2) by altering its shape without altering its charge (because change of shape occasions a change of distribution of electricity) ; (3) by altering its position (because the electrical condition of a conductor is always affected by that of other bodies in its neighborhood, on account of the mutual inductive action which takes place between them). The potential of any given body, therefore, depends on its shape, size and position with reference to other bodies.

It is now possible to explain what is the cause of the initial charge in an accumulating influence machine. It arises from the very slight potential difference existing between parts of the machine called the *inductors*, which fulfill the same office as the ebonite in the case of the electrophorus. This potential difference is increased by the action and re-action between the *carriers* (which correspond to the removable metal plates of the electrophorus) and the inductors. The carriers have charges induced in them by the potential difference existing between the inductors. They are then made to give up these charges to the inductors by contact, with the result that the potential difference between the latter is increased, and their consequent inductive action on the carriers made stronger, so that they are able to receive and convey more powerful charges. Since this process can be indefinitely repeated, a very small potential difference rapidly becomes a very large one, and the machine consequently able to produce extremely powerful effects.

In electrical study and practice it is often of great importance to determine what the exact potential of a body compared with some other body (often the earth) is. In order to fulfill this purpose instruments called *electrometers* are used.

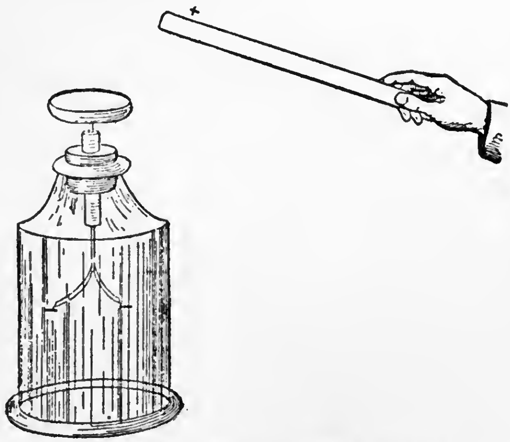

FIG. 5.—Gold Leaf Electroscope, showing divergence of leaves at the approach of a rubbed glass rod.

The most familiar is the "gold leaf electroscope." [1] It consists of two strips of gold leaf placed inside a glass jar, and suspended by a wire which passes through a glass tube fixed in the cork, stopping the mouth of the jar. This wire terminates in a knob or else supports a flat piece of metal. When the gold leaves are unelectrified they hang straight down, touching each other; but the moment any charge is communicated to them they diverge, being similarly electrified (see Fig. 5). This instrument is so sensitive that the smallest charge im-

[1] An *electroscope* is intended really to detect the presence and indicate the kind of electricity, but the gold leaf electroscope, though it can do this, is primarily a measurer of potential differences, and therefore an electrometer.

parted to it is made apparent. The chips cut from a cedar pencil and allowed to fall on the metal plate, are seen to be electrified, for as they touch the plate the leaves diverge. A rubbed glass rod approached within two or three feet from the instrument produces a marked effect, the gold leaves being then charged by induction. In the old form of this instrument, however (as depicted in Fig. 5), difficulties arose from the fact that if the glass shade were made as insulating as possible the gold leaves would feel the influence of *any* outside neighboring body, and therefore there could be no certainty with what the one under test was being compared. On the other hand, if the insulation of the glass shade was less carefully attended to, then the damp or dust collected on its outside would bring the latter to about the same potential as that of the earth, with which therefore the body under test could be approximately compared ; but then the imperfect insulation rendered it probable that directly the body was connected to the knob of the electroscope, it would be wholly or partially discharged, and therefore no longer of importance to test. Both these objections to the gold leaf electroscope have been overcome in the modern form of the instrument, devised by Professors Ayrton and Perry, in which the interior of the glass shade is coated with strips of tin foil, leaving only enough bare space to allow the gold leaves to be visible, and thus screening them from the influence of outside bodies, while the wire supporting the gold leaves passes through the top of the instrument, without touching it, thus greatly facilitating insulation.

It is curious to think that while the most advanced scientists are still unable to pronounce with any certainty what electricity is, they, and indeed every practical electrician, can measure this mysterious agent with the same unfailing accuracy that a tradesman can weigh out a pound of tea. Given any known combination of circumstances, and they will foretell precisely the behavior of electricity under those circumstances. There is a regular system of electro-static units, which need not be entered into here. They are based like the practical electro-magnetic units, of which a list and explanation will be given in a subsequent portion of this work, on the centimetre, gramme, and second as the units of length, mass, and time respectively.

As yet no source of electricity has been mentioned save friction, but there are many others, among the most important of which are magnetism, chemical action, heat, and the contact of dissimilar substances. The two first of these will require special chapters devoted to them, and the subject of thermo electricity also falls more properly under the head of current electricity.

With regard to the contact of dissimilar substances. Volta was the first to discover that two metals allowed to touch each other become feebly electrified in opposite ways, there being a much greater difference of potential[1] between some than between others. Thus when zinc is placed in contact with lead, it becomes slightly positive relatively to the lead ; in contact with copper it is much more decidedly positive, and in contact with platinum the difference of potential is very considerable indeed. Volta arranged a series of metals (to which a few have been added since his time) in which every metal becomes positive if placed in contact with one lower on the list. This list is given at the end of the chapter, as it may be found useful for reference.

Two dissimilar liquids in contact also show a difference of potential, as do a liquid and a metal, and a cold and a hot metal.

Other sources of electricity will be treated of as occasion requires, but it is worth while to notice how entirely we are so far justified in the conclusion that electricity is not made by the exciting cause, whatever that may be, but only obliged to manifest itself by being forced into an unnatural condition. One evidence of this lies in the fact that neither positive nor negative electricity can be produced alone ; an equal amount of the opposite kind is invariably forthcoming also. Another proof of the same thing is the possibility of charge by induction, in which the electrified state can be produced by mere influence, without any alteration in the quantity of electricity present. These considerations compel us to the belief that, whatever electricity may be, it is universally present, though we are often unconscious of the fact. Nor is this in reality a strange circumstance. It is probable that if the air were always in a state of perfect calm we should never know that such a thing as air existed.[2] We are rendered conscious of it by disturbances in its equilibrium, which cause the various winds. The same observation seems to apply to electricity. Some cause disturbs its equilibrium, and we then have too much of it in one place and too little in another, and the effort to restore equilibrium makes us conscious that electricity exists ; but when it is only present in its natural state, *i. e.*, in one of perfect equilibrium, we do not know it is there.

List of metals in which every one is electro-positive to that next in order—

+ Sodium	Copper
Magnesium	Silver
Zinc	Gold
Lead	Platinum
Tin	Carbon —
Iron	

[1] For convenience' sake a positively electrified body is usually said to be at high potential and a negatively electrified body at low potential ; but this is not really accurate, for there can be a high negative potential as well as a high positive one.

[2] See "Modern Views of Electricity," by Dr. Oliver Lodge, F. R. S.

CHAPTER IV.

THE LEYDEN JAR.

Importance of Leyden jar—Description—Electrical forces act across dielectrics—Capacity of conductors increased by proximity of opposite charge—And by earth connection—Definition of condenser—Discovery of Leyden jar by Cuneus—Method of charging and discharging—Residual charge—Important part played by dielectric—Real seat of charge—Bursting of jars—Battery of jars—Oscillatory nature of Leyden jar discharge—Further analysis of discharge—Sparking distance—Cause of its increase—Analogy with recoil—Cause of damping out and slackening of vibrations—Experiments by Dr. Oliver Lodge—Discharge of jar through circuit—Wheatstone's experiment—Velocity of discharge—Mechanical effects—Lichtenburg's figures—Magnetic effects of discharge—Physiological effects—Chemical effects.

THIS name is familiar to all, not excepting those "born in pre-scientific days;" for even then there were occasional quasi-scientific lectures given at schools and at country towns, at which the Leyden jar, thanks to its "shock"-giving capabilities, often played a prominent part, though it is doubtful whether the audience, or even in many cases the "lecturer" himself, understood the principle of its action. To electrical students of the present day this simple and, as some might suppose, antiquated apparatus is full of interest, for it involves facts as important and as wide-reaching as any of the more famous practical appliances of modern days; and only so recently as March, 1889, Dr. Oliver Lodge, in a discourse delivered at the Royal Institution, exhibited by means of the Leyden jar an entirely novel series of experiments illustrating some of the latest discoveries in electrical science.

The ordinary Leyden jar is a common glass jar, coated inside and outside to about four-fifths of its height with tin foil, and provided with a lid of dry, well-varnished wood, through which passes a thick brass wire, terminating on the outside in a metal knob, and communicating inside with the tin-foil, lining the inner surface of the jar. There are therefore two conductors, the two tin-foil coatings in presence of each other, separated by an insulating substance, *i. e.*, the glass jar. In Chapter I. it has been stated what happens when two conductors, one of which is electrified, are in close neighborhood and divided by the air. An induced charge in the originally unelectrified conductor is the result. If, instead of air, a sheet of glass were placed between the conductors, the induction would occur just the same; for glass and all insulating substances allow the electric forces to act across them, for which reason the name *dielectrics* is given to them. Though, however, all insulators are dielectrics, all are not equally good in this respect, nor does the best insulator make the best dielectric. Dry air is a more powerful insulator than glass, but it is not so good a dielectric, *i. e.*, the inductive force does not act so freely across it. This is fortunate, as if air were as good a dielectric as glass our thunderstorms would be more violent and frequent. Substances which serve well as dielectrics are said to possess a high *inductive capacity*.

It has already been stated that charges of opposite nature in presence of each other are bound. They cannot avail themselves of the road of escape to the earth, even if open, because of the attraction each feels for the other. It follows from this, and has been proved by experiment, that the capacity of a conductor is increased by having near it another conductor oppositely charged. The two charges act on each other so strongly, they are (if the expression may be permitted) so occupied with each other, that they produce hardly any effect on surrounding objects, and are barely influenced by them. A conductor thus situated appears to be at a very much lower potential than it would if it were removed from the neighborhood of the oppositely charged body. If it is desired to raise the potential of a conductor when in presence of one oppositely charged to the same degree as when not so, a very much larger quantity of electricity will be required, which is saying in other words that the capacity of the conductor has enormously increased.

There is another circumstance which increases capacity. This is if the charged conductor be in presence of one not only oppositely charged, but connected to earth; for, supposing the latter to have an induced negative charge, it will if connected to earth lose some of its positive electricity, the negative charge becoming in consequence much stronger, and attracting yet more positive electricity into the conductor whose charge is of this sign. Consequently, a conductor close to one oppositely charged, which has an earth connection, is capable of accumulating very large quantities of electricity, and an apparatus made on this principle and for this object is called an *accumulator* or more often a *condenser*. Having said thus much, we may return to the Leyden jar, which was the earliest known and is one of the best of all condensers.

Its name is derived from the place where it was first invented or, to speak more correctly, discovered, which happened by pure accident. In the year 1746 Cuneus, a scientist of Leyden, wished to electrify some water. With this object he placed the liquid in a wide-mouthed glass vessel, which he held in his hand, allowing a metal chain from the conductor of an electrical machine to dip into the water. After some time, thinking the latter must be sufficiently electrified, he took hold of the chain to lift it out of the vessel, when, to his intense surprise, he experienced a severe shock, which so terrified him that he let fall the vessel, and wrote a few days afterward to Réaumur that he would not expose himself to the same sensation again for the crown of France. What had really happened in the case of Cuneus and his glass vessel, was that he had unwittingly turned it into a condenser, the water serving as one conductor, his own hand as the other, and the glass, of course, as the dielectric. When, therefore, he connected the two conductors, by taking hold of the metal chain with his other hand, a discharge immediately took place through his body, occasioning the shock which so alarmed him, and which may be felt by any person who uses his hand to discharge a Leyden jar.

The ordinary method of charging is as follows: The jar is taken in the hand and its knob placed against the prime conductor of an electrical machine positively charged. Through the metal knob and wire positive electricity passes to the inner coating of the jar, and induces negative electricity on the outer coating, driving away the positive electricity of the latter to earth through the hand and body of the experimenter.[1] A stronger negative charge is the consequence, and its increased power of attraction draws more positive electricity into the inner coating, and the former process is repeated. The charging may be continued till the jar is electrified to the highest amount of which it is capable without bursting the glass, a contingency which always has to be guarded against. When charged, large sparks may be drawn from the jar by presenting the knuckle or one of the ends of a "discharging rod" to the knob—a discharging rod being simply a metal rod provided with glass handles, and jointed in the middle to allow of the two ends (which are knobbed) approaching each other. After the spark has been drawn the jar is found to be discharged, or, rather, apparently so; for if it be left some little time, and the discharging rod be then presented to it, a small spark may be drawn from it, showing that the jar could not have been entirely discharged by the first large spark. This second spark, which can never be obtained immediately, is due to what is called the "residual charge." Its return may be hastened by tapping the jar, which seems to show that its cause must lie in the molecules of glass not being able to return immediately to their natural condition after the strain put upon them, and its amount depends to some extent on the length of time the jar has been left charged, but also on the kind of glass of which it is made. In an air-condenser (a condenser formed by two conducting surfaces separated by air) there is no residual charge. This shows

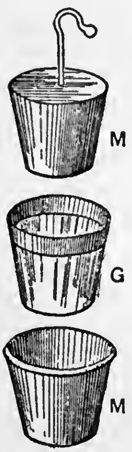

FIG. 6.—Leyden jar with removable coatings. M M, metallic cases; G, glass jar.

[1] An insulated Leyden jar will not charge, because the potential of the two coatings rises equally, unless, of course, the coatings are connected, when they can be charged as one conductor with electricity of the same sign.

at once that a very important part is played by the dielectric; and a still more striking proof of the same thing is given by the fact that the real seat of the opposite charges in a Leyden jar is not the tin foil coatings, but the inner and outer surfaces of the jar itself, as has been proved by means of a jar with removable coatings (Fig. 6). If, after charging, the latter are taken away, they are found not to be electrified; on being replaced their charges at once return. This seems to explain the reason of a charge being always apparently on the surface of a conductor; in reality its seat is on that surface of the dielectric which touches the conducting surface, and not on the latter. It is the effort of the electricity to enter the dielectric medium which causes the "charge," viz., an accumulation of electricity unable to disperse itself. The Leyden jar is in truth a type of all "charge" and "discharge" phenomena, and in particular its conditions, as we shall hereafter see, are precisely those obtaining between two thunder-clouds, or between a thundercloud and the earth. It is this typical character which invests it with so great an interest. A third fact concerning it, which has already been mentioned, that if too highly charged it bursts, *i.e.*, a hole is pierced in the glass dividing the inner and outer coatings, points to the true explanation of what happens to a dielectric placed between two charged conductors. It is thrown into a state of strain, which if too great causes it to break. In the case of air such a rent is self-mending; with glass, of course, it remains, and a Leyden jar thus pierced is rendered useless. An instructive and significant fact is that a vacuum acts as a dielectric, clearly showing that the strain can exist without the presence of ordinary matter. The conclusion is therefore justified that it must primarily take place in the ether,[1] and be by it communicated to air, glass and other dielectrics.

If a Leyden jar be made sufficiently large, it is evident that it might accumulate an enormous quantity of electricity; but as very large jars are found inconvenient in practice, it is more usual to connect them together in such a way that they can, if desired, be all discharged at the same moment. Such an arrangement is called a "battery" of jars, and, if the latter be of high capacity, is a very powerful source of electricity.

The spark from a Leyden jar is of infinitesimal duration, lasting only a small fraction of a second, and it was formerly supposed to be due to a single discharge. Such is, however, by no means always the case. When the spark is examined by means of a very rapidly rotat-

[1] The name given to an imponderable, tenuous, and highly elastic medium which pervades all space and interpenetrates all matter, and through which heat, light, and electrical energy are propagated by means of radiation. According to the latest scientific theories, all electrical phenomena are caused primarily by strains and stresses in the ether. Further reference will be made to this subject in the concluding chapter of the present work.

ing mirror, it is often seen to be serrated, proving that the discharge which causes it is not a solitary rush, but a number of surgings backward and forward, that the discharge is in fact *oscillatory*; and the rapidity of these oscillations is such, that some hundreds of thousands take place during the minute fraction of time which limits the duration of the spark. This fact throws light upon one which would otherwise be inexplicable, viz., that a Leyden jar is most inclined to burst, not, as would be naturally supposed, before, but at the moment of discharge—no doubt because the glass, though able to bear the continued strain in one direction (which is the condition of things in a "charge"), gives way when that direction is reversed and re-reversed with such inconceivable rapidity, its force of recovery (or elasticity) not being equal to the demand made upon it.

The fact of the discharge of a Leyden jar being oscillatory does not at first sight appear to be of any great importance, but when we recollect that all charge and discharge are like those of a Leyden jar we begin to understand that such a discovery as this is of the highest moment, and must be intimately connected with any true theory of the nature of electricity.

It is not necessary for the discharge of a Leyden jar to take place by means only of the discharging rod; there are many other ways in which it can be effected, some of them very interesting and instructive; but there is one way in which neither it nor any condenser arranged in the ordinary way with one coating connected to the earth will discharge, and that is by means of a continuous flow of electricity to the earth or to another conducting body.[1] If a wire is fastened to a single charged conductor, and then connected to earth or to another conductor, a flow of electricity begins and continues till the two bodies are at the same potential; just as water contained in two vessels connected together, one of which is fuller than the other, will flow from the fuller to the more empty vessel till the water in both is at the same level. But, as we know, a Leyden jar is not a single charged conductor; it consists of two conducting surfaces separated by a dielectric, and it has two charges, not one charge, which, being thus in presence of each other, are bound and will not flow away to the earth. When the discharge takes place, therefore, it is on account of the strain to which the dielectric separating the two electricities is subjected, breaking it down; so that either a hole is pierced in the glass, or a rent made in the air between the knob of the jar and the discharging rod. It is in this kind of discharge that a spark passes, and the distance it can overleap is called the *sparking distance*. This increases with the difference of potential. A much

[1] It is to be observed, however, that if a discharging rod were applied with great suddenness to a charged condenser of considerable size, much of the discharge would then take place in the form of a flow between the two coatings.

larger spark can be drawn from a Leyden jar when highly charged, so that the coatings relatively to each other are very positive and very negative, than when feebly charged. It is, in fact, difference of potential which produces the spark at all, and consequently the greater that difference is the greater the sparking power will be. The well-known mechanical phenomenon of recoil helps to explain this. The rebound of a spring which has been stretched to its utmost extent is very much greater than when it has been only slightly stretched; and this analogy may help us also to a clearer idea of the oscillatory nature of discharge. The spring, when let go, flies beyond its natural position and then back again, overshooting the mark on the other side, so that before it settles down a series of oscillations takes place. A plucked violin string gives an example of the same thing; and it is what frequently happens in the case of the Leyden jar. Its discharge is then a series of partial discharges, caused by the electricity overshooting the mark and swinging back again, just as the spring or the violin string overshoots the mark and swings back again. The inner coating of the jar at the instant the discharge begins is positive; it then becomes momentarily negative, to return again to positive, and then back to negative, the charge becoming feebler with each vibration till it is entirely dissipated, just as the oscillations of the spring become smaller and smaller in range till they cease altogether and it is at rest. Clearly the greater the resistance the spring has to encounter in making these movements, the fewer they will be and the sooner they will cease; and we may illustrate the same fact by a pendulum. In air it will oscillate for a considerable time. In treacle it will not oscillate at all, but simply return to its position of equilibrium with a slow, sliding motion. The same thing is true of a Leyden jar discharge. The electricity may encounter very little resistance on its road, or it may encounter a good deal. In the former case the oscillations will be many and rapid; in the latter, few and slow; and it is even possible, as in the case of the pendulum in treacle, to put a stop to them altogether. The same effect as that of resistance may be produced by weighting a spring. A heavy violin string vibrates much more slowly than a light one; and something analogous to the adding of weight, but which cannot here be explained, may be done in the case of electricity.[1] Acting on this principle, Dr. Oliver Lodge was able to show some very remarkable experiments at the Royal Institution in March, 1889. He brought down the number of vibrations in a Leyden jar discharge from their usual frequency of about 1,000,000 a second to 500 a second, with the result that the sudden sharp crack of the spark was changed into a distinct musical note, and the line of light was seen

[1] It is accomplished by increasing what some electricians call the "self-induction," and others the "electro-magnetic inertia" of the circuit. See p. 78.

by the audience to be quite coarsely serrated by means of a mirror revolving only four times a second.[1]

It has already been said that a Leyden jar can be discharged in various ways ; for instance, instead of a discharging rod being used, and one end made to touch the outer coating, while the other is approached close to the knob connected with the inner coating, wires may be fastened to each of the coatings and made to pass round a considerable space, or coiled many times on themselves, before their respective free ends are brought near together. When this is done, however, a spark passes between the two, just as it does between the discharging rod and the knob of the jar. Such an arrangement is called a *circuit*, and several intervals may be left in it, all of which the spark will overleap, provided their united length does not exceed that which it could pass at one jump.

Apparently the discharge takes place as instantaneously when the electricity has to travel through many yards of wire before arriving at "sparking distance" as when the discharging rod is used. This is not really the case, however ; and by a celebrated experiment (which, broadly described, consisted in connecting each of the coatings of a Leyden jar with a considerable length of wire, and arranging three small intervals side by side across which sparks had to pass)[2] Sir Charles Wheatstone determined the velocity of transmission through copper wire to be at the rate of 463,133 kilometres or 288,000 miles a second. Other experimenters have, however, obtained different and very much slower rates, and in any case it must not be supposed that this experiment really proved anything at all about the "velocity of electricity." It simply showed that through a conductor of given resistance and capacity a certain electric effect took a definite though infinitesimal time to travel, which would not be the same through a conductor differing in either or both of these respects.

The heating and luminous effects of discharge have been already mentioned. Its mechanical effects are of equal importance and interest. The electric whirl is one of these. Another is the perforating of paper or cardboard by passing the electric spark through them ; and a remarkable fact is that the edges of the paper round the hole

[1] For a detailed report of the above experiments and the discourse which they illustrated, see *The Electrician* for March 15, 1889.

[2] The test was as follows : The central interval was that which the spark had to pass *after* the two electricities had made the journey through their respective wires ; the side intervals they encountered almost immediately. If the transmission had been instantaneous, the sparks examined in the rotating mirror would have presented three parallel lines. Instead of this their appearance was thus when the mirror turned from right to left, and thus  when it turned from left to right, showing that the central spark began after its companions, and also proving the double flow, since one side interval was in the wire coming from the negative, and the other in that from the positive coating.

will be found turned up on *both sides* instead of only on one, as in an ordinary perforation by burning. Formerly this was supposed to be a proof of the double current; it is now, however, rather considered to be a consequence of the mechanical effects of the current spreading equally in all directions. Lichtenburg's dust figures also show the mechanical power of electricity. They are made by means of two powders (often vermilion and sulphur) being shaken together in a muslin bag and then sifted on to a cake of resin. The friction causes the powder particles to become electrified, the vermilion positively and the sulphur negatively, consequently the negative parts of the resin attract the vermilion and the positive the sulphur, so that the two powders arrange themselves in distinct and quite different shapes.[1]

Of other effects of discharge, that on the magnetic needle must be mentioned. It is deflected from its true position when close to the place of discharge; and during violent thunderstorms ships' compasses have often been rendered quite useless, owing to the influence of the lightning on them. A steel needle may be made into a permanent magnet by being placed within a wire spiral through which a discharge is passed. Discharge also produces considerable physiological disturbances, which are most strikingly illustrated by lightning, and will therefore again be referred to under the head of atmospheric electricity; but powerful electrical machines and Leyden jar batteries can produce effects quite as marked, and sometimes fatal where proper precaution is neglected. Even a single ordinary jar may give a very unpleasant shock, as Cuneus and many others have proved. The "return shock" experienced by persons standing at a little distance from an electrical machine which is being discharged, or from some object "struck" by lightning, is due to induction. The effect of the charged conductor (whether a cloud or the prime conductor of a machine) is to induce a charge of opposite kind in all neighboring objects. When it discharges, they follow its example, their charges being no longer bound, and the consequence to a living body is a "shock."

Lastly, a discharge passed through chemical compounds causes their decomposition, and its effect on the air, as we have already seen, is the production of ozone.

[1] Another way of making these figures is by tracing a pattern on the resin with the knob of a charged Leyden jar and then sifting the powder over it.

CHAPTER V.

ATMOSPHERIC ELECTRICITY.

Identity of lightning and electricity—Franklin's kite experiment—Its repetition by Romas—Danger of these experiments—Death of Richman—Existence of atmospheric electricity independently of thunderstorms—Results of modern observations—Daily variations—Annual variations—Electrified clouds—Signs of atmospheric electricity in dry, cold weather—Ozone—Its importance to health—Not found in contaminated air—Same true of positive electricity—Ozone an active chemical agent—The Aurora Borealis—Frequent appearance in high latitudes—Description—Resemblance to discharge through rarified gases—Probable origin—Effect on the magnetic needle—Improbability of its being attended by sound.

MANY early observers noticed the resemblance between the flash and crack of the electric spark and those tremendous natural manifestations, lightning and thunder. It was reserved for the great American philosopher, Benjamin Franklin, however, to establish their identity by actual experiment. Having observed that lightning usually strikes the most elevated objects, he resolved to erect a sort of sentry-box on some high tower, from which a pointed and insulated rod could be raised, and thus enable him to make his observations. Before this could be accomplished, his fertile brain suggested another expedient to which resort could be had the first time a thundercloud approached, and which therefore he determined to adopt. This was to use a common kite, suitably prepared. He made one of silk, fastened an iron point to it, and furnished it with a string, the upper part of which was of ordinary twine, but the lower part of silk. At the junction of the two he attached a key. At the first sign of a thunderstorm he went out into the country, accompanied by his son, and let fly the kite. At first, to Franklin's intense disappointment, no signs of electricity were obtained, but in a short time he noticed the loose fibres of the string begin to bristle, and holding his knuckle to the key, a bright spark passed between the two. Rain then fell, the string became wet, and its conducting powers consequently much better ; and in a short time numerous large sparks were drawn from the key, proving beyond a doubt that Franklin's surmises were correct, and lightning and the electric spark identical. This celebrated experiment was made at Philadelphia in 1752.

In 1753 it was repeated on a very grand scale by the Frenchman Romas, and in presence of several spectators, Romas himself receiving a very severe shock, which warned him to use a discharging rod instead of his knuckles to draw the sparks, the latter being so powerful that they appeared like flashes of fire a foot long, and were accompanied by a noise audible at 500 feet distance. At the commencement of this experiment no rain was falling ; when it began to do so a great increase of electricity was perceptible, and Romas dared not draw sparks even by means of the discharging rod. Both he and the bystanders experienced the peculiar sensation, "as though a spider's web had been upon the face," which is sometimes felt near an electrical machine, and the explosions and flashes of fire were attended by the strong and characteristic smell accompanying a violent lightning discharge and the working of electrical machines. This odor was described by nearly all early observers as "sulphurous," but in reality it more resembles that of phosphorus, and is now known to be due to the production of ozone.

It is evident that experiments of this description, unless conducted with the very greatest care, are in the highest degree dangerous, and before long a fatal accident checked the growing ardor of the scientific world for making them. On the 16th of August, 1753, Professor Richman, of St. Petersburg, while conducting experiments during a thunderstorm on an insulated iron rod, projecting from the roof of his house and carried down into the room where he worked, was killed by a sudden flash of electric fire which darted from the rod with a loud report. So terrible a warning was not unheeded, and experiments on lightning became very rare; in fact, it may be said that since this period hardly any have been undertaken, though many facts and observations have been collected, and the rapid growth of electrical science has enabled practical men to grapple, to a very great extent successfully, with the problem of protection from injuries to life and property due to lightning.

Before entering upon the subject of thunderstorms, which are occasioned by an abnormal electrical condition of the atmosphere, it will be well to glance at what that condition is when no storms are in progress.

The discovery that electricity exists in the atmosphere quite independently of thunderstorms was an almost immediate consequence of Franklin's famous experiment with the kite. The Abbé Mazeas discovered in 1753 that signs of atmospheric electricity could be obtained in fine dry weather at all hours between sunrise and sunset; and Franklin himself attached a pointed iron rod to his house, which could be insulated when he chose, and to which he connected a system of the electric chimes previously described. Whenever the conductor was affected by the neighborhood of some charged cloud, the chimes began to ring, and Franklin's attention was drawn to the fact that a favorable time for his observations had arrived. His apparatus did not enable him to ascertain more than that ordinary clouds were sometimes positive and sometimes negative, more often the latter; and no very great advance was made in the knowledge of atmospheric electricity till the electroscopes and electrometers of modern days were applied to this purpose. And even now but little has been positively ascertained on this subject. From observations made at various times in different places, and compared and verified by eminent men of science, the following facts have, however, been elicited. The potential of the air increases with increase of distance from the surface of the earth, which might be caused by the latter possessing a negative charge, but it is not known whether this is really the case. In fine, calm weather, the atmosphere is positive;[1] in cloudy, rainy and windy weather it is very often negative, but will sometimes change rapidly from one sign to the other. Clouds are always electrified, and often to a very high potential. Usually they are positive, but there are many exceptions. The electrical condition of the air is subject to daily and annual variations. Every twenty-four hours there is a decrease of electricity, beginning an hour or two after midnight and continuing till shortly before sunrise, when an increase commences and goes on until some hours after sunrise, when the first maximum is attained. The electrical condition of the air then remains stationary for a short time, after which another decrease sets in until some hours after noon, when a minimum is reached. Another short pause ensues, and then a second increase takes place, attaining its maximum some hours after sunset. Then occurs the second decrease, reaching its minimum about midnight. Many local causes, however, may modify the ordinary electrical condition of the air and its daily variations. Fogs are highly electric, and their presence always considerably raises the potential of the atmosphere. Snow-storms accompanied by high wind are sure to produce very strong indications of electricity, and this fact favors the idea that one important source of atmospheric electricity may be the friction against each other and the earth of solid and liquid particles, brought about by the wind.

The annual variations of atmospheric electricity consist in a gradual increase beginning from May or June and attaining a maximum in one of the winter months, varying with the locality in which the observations are made, and a gradual decrease commencing from the time of maximum and continuing until a minimum is reached in the early summer. It is, therefore, during the winter months that the air is most highly electrified, a circumstance which may perhaps surprise those who are accustomed to think of thunderstorms as the only signs of atmospheric electricity, for these in our climate are far more common in summer than in winter. It is not, however, a uniformly high potential which occasions storms, but great differences of potential, and these occur in England more frequently in summer than in winter, owing to the larger amount of evaporation which is going on.

[1] The lower strata of the atmosphere are non-conducting when dry. It is at some distance above the surface of the earth that indications of positive electricity are obtained. According to some recent observations, earthquakes appear to occasion a negative electrification of the air.

Vapor in considerable quantities rises from the earth and sea, drawn up by the heat of the sun, and on reaching the higher and cooler layers of air, condenses. Now, evaporation has been proved by experiment to be always attended by a development of electricity ; and the vapor particles are therefore all in an electrified condition. When they condense into a drop, their united electricity spreads itself (according to the laws of electrical equilibrium) over the surface of the drop, which, however small it may be, is far more highly electrified than any one of the vapor particles which have gone to form it. These minute drops again coalesce into larger ones, with the result of a still further raising of potential, and a cloud which is formed of an incalculable number of such electrified drops attains a very high potential indeed, and becomes capable of exerting a strong inductive influence on neighboring clouds and on the earth, and thus of giving rise to thunderstorms. Though atmospheric electricity is not indicated in this way during winter, or at any rate but rarely, it gives other less obtrusive signs of its presence. It is in the winter months that single well-isolated objects become most easily electrified ; every one knows that the peculiar crackling of the hair when combed occurs almost invariably in dry frosty weather, and articles of clothing will also then frequently show signs of electrification. Rubbing the hand briskly against flannel or any woolen material, occasions a crackling noise accompanied, in the dark, by sparks ; and brushing woolen garments will often cause them to become more dusty than before, owing to the friction electrifying them and making them attract small floating particles of matter. In New York, where very dry and intense cold is experienced in winter, these electrical effects are very marked ; the dryness of the air in dwelling houses being increased by the method of warming, and the insulation of different objects by the thick woolen carpets used. It is stated that "if one move upon such a carpet with a sliding or scraping motion, and then present the knuckle to a metallic conductor, such as the handle of the door, an electric spark accompanied by a crackling noise will be perceived. If one goes in this way once or twice quickly along the carpet, the spark may be three-quarters of an inch long, very brilliant and accompanied by a tolerably loud noise."[1] In order to observe these phenomena well, the carpet should be entirely of wool and thick. The authority above quoted gives an amusing account of a visit to a lady in New York in a house where the conditions were particularly favorable. She drew brilliant sparks from the gas chandelier ; a visitor advancing to shake hands with her, would receive a perceptible shock, and a spark would pass between herself and a lady friend bending to salute her.

The dry cold weather which is best adapted to the manifestation

[1] "The Thunderstorm," p. 289.

of these and kindred phenomena is considered particularly favorable to health, most persons then experiencing a feeling of much greater physical briskness and activity ; and it does not seem improbable that this may be partly owing to the more highly electrified state of the air. In any case, electricity must certainly be considered an important salubrious agent, for to it we apparently owe the existence of ozone, on the necessity of which modern sanitarians insist so strongly. As has already been stated, ozone is a modified and much more active form of oxygen. Its presence in large quantities (as during the working of an electrical machine) is made known by a strong and peculiar odor, but in thoroughly good and pure air there is always a small amount of ozone, and its absence is a sign that the atmosphere is in some way contaminated. It is not found in crowded rooms, in the confined courts of large cities, or in any place infected by the breath of men or animals. In the open squares of towns, on bridges and quays, and, in fact, wherever the air is easily renovated, and consequently pure, indications of ozone are readily obtained ; and it is worth while to observe that the same remarks apply to positive electricity, no traces of which are discoverable in close and confined quarters, or in crowded streets and dwellings. Beside its health-giving properties, ozone is an active chemical agent ; it is a very rapid oxidizer, and possesses strong bleaching powers ; and organic substances exposed to its influence are corroded.

The last and most remarkable electrical phenomenon which will be mentioned in this chapter is the Aurora Borealis. All travelers in the far north are well acquainted with its changeful and exquisite light, so vivid as to clothe with glory the winter darkness of the Arctic regions ; but even in England the Aurora is often visible, though far less brilliant than in higher latitudes. On one occasion, in early winter, the writer witnessed an exceptional display of its beauty. The whole northern horizon was covered with a deep rosy glow from which pale streamers extended far up into the heavens. Even this, however, was but a faint representation of the "Northern lights" as they are known to the inhabitants of the Polar regions, where they are described as often equal to the full moon in brilliancy, appearing in the most exquisite arches, continually melting one into the other to reappear in new and more beautiful forms, and varying in color from a silvery whiteness to deep shades of orange and rose color. The motion of the auroral streamers which start from the arches or glow is often exceedingly quick, and has gained for them among the inhabitants of the Shetland Isles the name of "The Merry Dancers." They change rapidly in form, die away in one place to break out in another, and are generally animated by a strong tremulous motion from end to end. This tremulous motion is like the flickering of the light caused by passing an electric spark through an exhausted tube, and, in fact, the two phenomena resemble each other almost as closely as do the electric spark and a flash of lightning. It is therefore natural to refer their existence to a similar origin, and the Aurora Borealis is considered to be due to electric discharges taking place in high and therefore very rarefied strata of the atmosphere. The actual proof that its origin is electric lies, however, in the fact that the presence of the Aurora invariably affects the magnetic needle, making it deviate from its true position, and that often to a considerable extent, and over very large areas of the globe. The Aurora does not always appear in the due North, but frequently toward the East or West, and sometimes at both points simultaneously; neither is it always arched, but appears occasionally in strips, or in "undefined luminous clouds." Its position in the heavens is thought to affect the weather; thus after an Eastern Aurora, dry cold is expected, whereas one in the West is supposed to cause storms and snow, and Auroræ in both quarters simultaneously, unsettled weather.[1]

Early travelers frequently said that a peculiar "hissing, crackling, and rushing noise" accompanied very brilliant displays of the Aurora, but no such sound has ever been heard by any scientifically trained observer, or, indeed, by any observer at all in modern times; and the fact of the Aurora taking place in very rarefied air, renders its being accompanied by sound highly improbable. The appearance of these heavenly fires, which is frequently such as to give the impression of their being carried along by an impetuous wind, irresistibly suggests the idea of a "rushing" sound as their fit accompaniment, and this may easily have given rise to the belief that it had been actually heard.[2]

The Aurora is seen in the South Polar regions as well as in the North, and is then called the "Aurora Australis;" but these Southern lights, though still very beautiful, are not so striking and brilliant as the Northern.

[1] "The Thunderstorm," p. 299.

[2] M. Gaston Planté nevertheless credits the reality of this sound, and attributes it, as he does that which accompanies globular lightning, to the sudden vaporization of liquid particles by the passage of the electric discharge ("Phénomènes électriques de l'Atmosphére," p. 146).

CHAPTER VI.

ATMOSPHERIC ELECTRICITY CONTINUED—THUNDERSTORMS.

Analogy between Leyden jar and conditions giving rise to thunderstorms—Reason of repeated discharge in the latter—Short duration of lightning—Brilliancy—Color of lightning flashes—Shape—Forked lightning—Cause of ramification—Possibility of the light of one flash producing another—Bifurcation—Sheet lightning—Thunder—Globular lightning—Planté's experiments—His conclusions from them—Chemical effects of lightning—Heating effects—Fulgurites—Explosive effects—Probable cause—Examples—Length of lightning flashes—Altitude of thunder-clouds—Magnetic effects of lightning.

IT was stated in Chapter IV. that the conditions giving rise to thunderstorms are the same as those of a charged Leyden jar. We may go a little further than this, however, and say that possibly the inhabitants of the earth live in a huge Leyden jar, which is usually but slightly charged, but may at almost any moment become electrified to a very high degree. The earth's surface, which there is reason to believe may be always faintly negative, would form one coating of this jar, the clouds and upper strata of the atmosphere the other, and the air between would be the dielectric. Now, if owing to rapid evaporation and condensation, or to other of the various causes which generate and increase atmospheric electricity, clouds form whose potential is very high, they act inductively on the surface of the earth and all objects which rise from it, and these become strongly charged in the opposite way, the air between the clouds and the earth being thrown into a state of strain exactly similar to that of the glass in a Leyden jar. By and by this strain becomes so great that the air gives way under it, a rent is made, a dazzling flash of lightning is seen, a loud roll of thunder heard, and a beginning of discharge is made; but a beginning only, for, as we well know by experience thunder-clouds do not discharge themselves at once like Leyden jars; the lightning and thunder will often continue for hours with but little interval between the flashes, and no diminution in their brilliancy. The reason of this lies in the way in which clouds are formed of innumerable drops, each one electrified and each one insulated from its neighbor. Because of this a cloud is electrified throughout its whole mass, and not only on its surface; therefore, so soon as one surface discharge is over, more electricity replaces that which has been dispersed, and a similar state of strain recurs, to be relieved by another discharge, rarely, however, following exactly the same path as its predecessor. Discharges take place between different clouds, as well as between clouds and the earth. In the former case there may be no danger to be apprehended, but in the latter very serious and alarming consequences often ensue; though the use of lightning rods, imperfect as the latter may still be in some respects, has certainly diminished the number of accidents to life and property.

The two principal characteristics of lightning are its short duration and its extreme brilliancy. A flash of lightning is thought to last about one ten-thousandth part of a second. This fraction of time is so minute that it is difficult to form an idea of it, but a rough notion of the momentariness of lightning can be obtained by observing that an object moving at however great a speed, the wheels of a carriage, or of a train, appear absolutely stationary when seen by it. Even a rifle ball would look as if poised motionless in mid-air. One experiment which has been made proving this extremely short duration of lightning, is to observe during a flash a very rapidly rotating disc, painted in alternate black and white sectors, running from the centre to the edge like the spokes of a wheel. By daylight such a disc appears gray while revolving, as its speed is so great as to allow no time for the eye to distinguish between the black and white, which are consequently mixed together and form gray. Seen by a lightning flash, however, the black and white sectors stand out clearly with gray ones between them, the fraction of space through which one sector is able to move while the flash lasts being so small as to produce almost the same effect as though it were stationary. In order to produce exactly the same effect and have no gray at all, it would be necessary for the illumination to be really instantaneous, which is impossible.

One consequence of the short duration of lightning is an apparent diminution of its brilliancy. It has been proved that light cannot produce its full effect on the eye unless it remains, at least, as long as one-tenth of a second. But lightning lasts only the ten-thousandth part of a second, and it follows from this that we see it one hundred thousand times less bright than it really is. When we recollect that even thus diminished its brilliancy is such as to cause temporary blindness if too closely watched, we may feel grateful that we cannot see it in its true vividness, for any human powers of vision would be too weak to bear such a sudden and overwhelming illumination.[1]

The color of lightning varies according to the condition of the atmosphere. If the latter be saturated with moisture, red will probably be the predominating hue, because the intense heat developed by the passage of the flash decomposes and rarefies the air and the watery vapor it contains. If, therefore, the latter be abundant, rarefied hydrogen, which is red when an electric discharge passes through it, will give its hue to the lightning. If, on the contrary, the air be

[1] It should be stated, however, that there is some evidence, chiefly photographic, that lightning flashes may at any rate occasionally be of longer duration than is usually supposed, and the magnetizing power of lightning also points to this conclusion. See the discussion on lightning-rods during the meeting of the British Association at Bath, 1888.—*Report of the British Association* for 1888, pp. 593, 598, 601.

comparatively dry, or the quantity of electricity in play not very large, the color of the flashes will be blue or bluish-violet, which is that of rarefied air during the passage of an electric discharge.[2]

The shape of a flash of forked lightning varies according to its length, and the equality of resistance it encounters in its path from a cloud to the earth, or from one cloud to another. If the distance be short, and the air of a tolerably uniform density, the flash may be nearly or quite straight; but if there is a long way to traverse, and the air is in different states of density at different points (as is almost invariably the case during a thunderstorm), the flash is sure to pursue a very irregular and winding path, sometimes seeming to meander

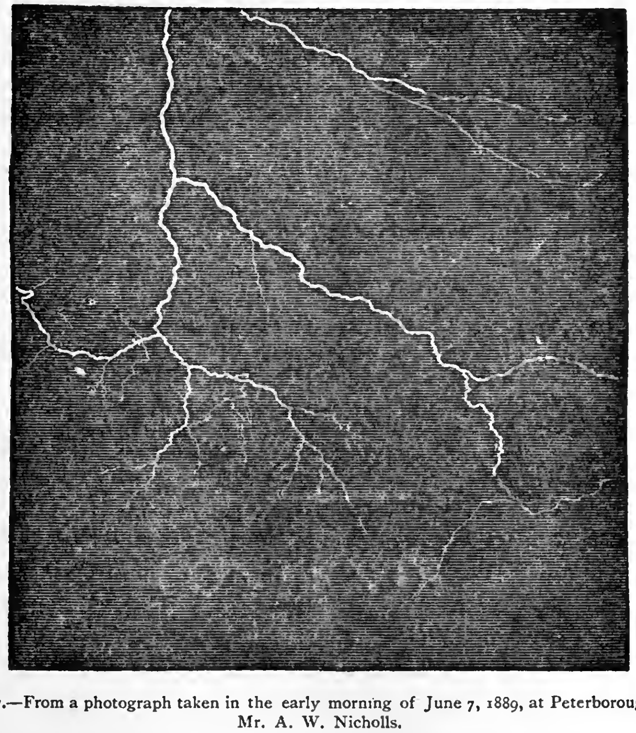

FIG. 7.—From a photograph taken in the early morning of June 7, 1889, at Peterborough, by Mr. A. W. Nicholls.

about in the air, sometimes even making loops and knots in its progress (Fig. 9), and in all cases frequently giving out side flashes, as represented in Figs. 7 and 8.

The cause of the irregular path of a lightning flash lies in the tendency of electricity to take the path of least resistance; it would rather run round an obstacle, if possible, than overleap it, and a long electric spark will often exhibit on a small scale exactly the same peculiarities of shape as a flash of lightning, and for the same reason.

[2] Planté, "Phénomènes électriques de l'Atmosphére," pp. 34, 35.

The forking or, to speak more correctly, the branching of the lightning (for, seen in a photograph, one flash often seems to ramify into others, like the roots or branches of a tree, Fig. 7) has a different

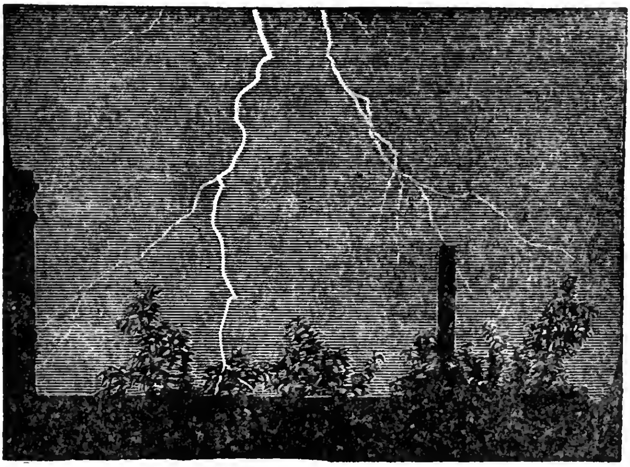

FIG. 8.—From a photograph taken by Mr. C. A. E. Pollock, at Corpus College, Cambridge, on the night of June 6, 1889.

cause. It is thought that one lightning flash gives rise to others following nearly, though not quite, the same direction as itself; and

FIG. 9.—From a photograph by Mr. A. K. Baird, taken at Edinburgh, on June 6, 1889, about 9 P. M.

when we remember that the cause of lightning is the break-down of the air under the strain to which it is subjected, this hypothesis becomes exceeding probable, for all round the path of the flash, and not only in it, this same strained condition obtains, so that the mere shock of the air giving way at one point would seem to render its giving way at the other neighboring points almost a matter of certainty.

There is another way in which one lightning flash may, perhaps, be the cause of others—a way which is particularly interesting because it serves to show the exceedingly intimate connection between light and electricity. It is a curious and remarkable fact that if the light of an electric spark is made to fall on the space between two conductors, which are highly charged but just not able to spark into each other, they will at once do so, especially if the light fall on the conductors themselves—showing that under certain conditions the mere effect of light is able to produce an electric discharge. Now, since lightning is in reality simply a very enormous electric spark, it is only reasonable to suppose that it will behave like one, and, therefore, that

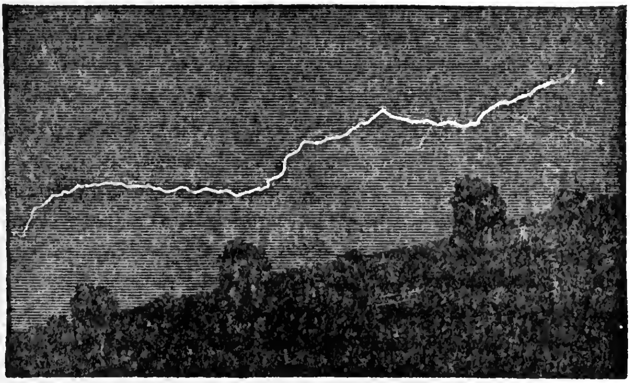

FIG. 10.—From a photograph taken in the early morning of June 7, 1889, at Peterborough, by Mr. A. W. Nicholls.

under some circumstances the *light* of one flash will cause another flash. The probable reason of this phenomenon can only be briefly alluded to, but it is of too great interest to be passed over entirely. It has already been stated both that the discharge of a Leyden jar is often oscillatory and that it is the type of all discharge, including that of lightning. It follows, then, that lightning discharge may be oscillatory. Now, in a medium able to transmit them, oscillations or wave-movements spread; and with light and electricity the ether is the medium through which they spread, as air is the medium through which sound waves spread. In the case of sound, it is well known that if two tuning-forks of the same pitch be placed near each other, on striking one the other will give out its note also; this is because the vibration of the first, communicated through the air to the second, sets up in that a similar vibration. It would seem that an electric spark, or a flash of lightning caused by the light of another spark or flash, must have an analogous origin. A vibration is set up by the first flash, which is communicated through the ether to the point where the state of things is such that another similar vibration can be set up, and a second flash is the result. Such a combination of conditions may be rare (it is not always that we find two tuning forks near at hand able to be excited the one by the other), but it is certainly possible, and its occurrence, if it could be proved, of the very highest interest.[1]

A single flash of lightning will sometimes divide when it strikes an object, and take two or even more different paths for the rest of its journey to the earth, working destruction in each, unless very efficient lightning conductors be provided. Some description of these and the injurious effects they are intended to guard against, will be given shortly. In the meanwhile mention must be made of the second kind of lightning flash, the *sheet*, and of a third, which is not a flash at all and is but seldom seen, viz., *globular lightning*.

Sheet lightning presents the appearance of a broad flash, emanating from the edge of the cloud, or occasionally from the centre, when the cloud looks as if it opened to allow of the exit of the electric fire. No object on the surface of the earth is ever struck by it; it is, in fact, a discharge between cloud and cloud, much of the nature of a brush discharge, and not a discharge between a cloud and the earth. Occasionally sheet lightning is seen on a clear sky and unattended by thunder, and it is then often called summer or heat lightning. This is no doubt reflection of flashes from a storm below the horizon, and too distant to allow the sound of the thunder to reach the ear of the observer. The thunder itself is supposed to be due to the sudden and violent expansion of the air caused by the enormous heat developed in the path of the lightning. The rolling sound is occasioned partly by echoes from the different surfaces of the clouds and from strata of air of unequal density, and partly by the great length which a lightning flash sometimes attains. The flash is practically simultaneous along its whole path, but since sound takes a very much longer time to travel than light, moving at the rate of only about 1,100 feet

[1] Professor Rowland appears to think that the "return shock" (which in the case of a lightning flash often takes place at a very considerable distance from the actual point of discharge), may be explained on a similar principle. In a lecture given at New York, before the American Institute of Electrical Engineers, he said: "If they (the oscillations) take place, we have a ready explanation of what is sometimes called a back-stroke of lightning. That is, a man at the other end of the cloud, a mile or more distant from the lightning stroke, sometimes receives a shock, or a new lightning flash may form at that point and kill him. This may be caused, according to our present theory, by the arrival of waves of electrical disturbance, which might themselves cause a slight shock, or even overturn the equilibrium then existing, and cause a new electric discharge."

a second, the noise of the thunder, though started at the same time throughout the entire line of discharge, reaches the ear by degrees, the sound from the nearest point first and that from the points farther away afterward, according to their distance.

Globular lightning, *i. e.*, lightning having the appearance of an intensely brilliant luminous or fiery ball, was long held to be fabulous, and the accounts of it have certainly often been greatly and even ridiculously exaggerated. Nevertheless, there remains now no manner of doubt that this phenomenon, though rare, compared to that of forked or sheet lightning, does most unquestionably occur.[1] Persons trained to scientific observation have recorded its appearance, and their accounts tally in the main particulars with those of other observers. Globular lightning may either descend from the clouds[2] or ascend from the earth,[3] or it may float along at a greater or less distance from the soil.[4] Its movement is slow and its path often extremely capricious. Its duration varies from a few seconds to a minute or more. Its disappearance is sometimes noiseless and harmless, sometimes attended by a loud explosion and disastrous effects. Some accounts have described these fiery balls entering the window of a house and going up the chimney. This is probable enough, as the column of hot air would make an excellent conducting path for the electric discharge. Owing to the same cause, no doubt, there have been accounts of similar visitors coming down the chimney, to the great consternation of the witnesses. Globular lightning has been observed in the centre of thick clouds during a thunder-storm, and passing between one cloud and another,[5] and also occasionally with a rotatory movement.[6]

Many of the phenomena of globular lightning have been artificially reproduced on a small scale by the late eminent French electrician, M. Gaston Planté, whose experiments were, however, conducted by the aid of current, not static electricity. He used powerful secondary

[1] The writer in the year 1870 herself witnessed an appearance of globular lightning. It occurred in Wiltshire during a heavy thunder-storm, which, not being immediately overhead, allowed of a continued observation of the lightning flashes. These presented nothing specially remarkable. The storm was in the neighborhood of the Westbury Downs, at some distance above which there was a thick, leaden canopy of cloud. Toward the end of the storm there fell from this cloud an egg-shaped luminous body which apparently dropped to some point on the hills, where it disappeared. Some seconds afterward there ensued a long, heavy roll of thunder. As the hills are distant about three miles, as the crow flies, from the place where the writer was situated, this luminous globe would appear to have been of considerable size. Its brilliancy was apparently that of ordinary forked lightning observed from the same distance, but its motion very much slower, the globe remaining visible for two or three seconds. No rain was falling at the time.

[2] "Phénomènes électriques de l'Atmosphère," p. 201 ff.

[3] *Ibid.*, p. 214 ff. Forked lightning also, though rarely, ascends.

[4] *Ibid.*, p. 47. [5] *Ibid.*, p. 207. [6] *Ibid.*, p. 202.

batteries,[1] which give currents of a very high potential, and succeeded by their means in producing small and intensely brilliant globules of fire on the surface of water, on a sheet of mica placed between two conducting surfaces, and lastly in the air-space between two damp sheets of filtering paper.[2] These luminous globules behaved in the same manner as globular lightning. They moved slowly, followed, in the second and third cases, very irregular paths, and their duration was considerable. M. Planté was led by his experiments to the conclusion that globular lightning must be produced by "dynamical" electricity (*i. e.*, current electricity) of very high potential and in large quantities, and that the fiery globes themselves are formed of "rarefied incandescent air and of the gases resulting from the decomposition of vapor of water also in a state of rarefaction and incandescence."[3] The brilliancy of these globes is due, according to M. Planté, to the quantity of electricity in play at the time of their appearance, and it is a fact that they are only observed during storms of exceptional severity. The rustling noise which often accompanies them he refers to the rapid vaporization of liquid and solid particles in the path of the electric discharge, and the variation of color to the same cause which produces it in ordinary lightning.[4]

Lightning produces chemical changes similar to, but on an enormously larger scale than those of an electric spark. It is often attended by a copious generation of ozone, to which fact may be referred the powerful odor often mentioned by persons who have been near an object "struck" by lightning. It also decomposes the oxygen and nitrogen of the air in order to form nitric acid, strong traces of which are found in specimens of rain-water collected during thunderstorms, while at other times it is either entirely absent, or present in almost infinitesimal quantities. The heating effects of lightning are also very great; it fuses and even vaporizes metals; but perhaps the most wonderful examples of its power in this way are the fulgurites or tubes of vitrified sand found in many places, and now known to owe their origin to lightning. Some remarkable tubes of this kind were found near Drigg, in Cumberland, in 1812, one of which was considerably more than thirty feet in length, and varying in diameter from an inch and a half, at the surface of the sand hill in which it was found, to half an inch at the bottom of the excavation made. Small branches, two or three inches long, and a quarter of an inch in diameter, protruded from the main stem. The outer surface of these tubes was rough and uneven, but the inner surface was formed of a "whitish or limpid vitrified matter, covered with a smooth glaze, and hard enough to scratch glass."[5] Similar tubes were found by Darwin in South

[1] See Part III. chap. i. p. 77.

[2] "Phénomènes électriques de l'Atmosphére," chap. i.

[3] *Ibid.*, pp. 29, 30. [4] See p. 40. [5] "The Thunderstorm," p. 117.

America, near the River Plata,[1] and attempts have been made with partial success to imitate them artificially, by means of passing a powerful electric discharge through various hard, powdered substances. The experiments succeeded with glass dust, a tube an inch long having been formed in this way, but failed with felspar and quartz, out of which lightning has nevertheless manufactured tubes thirty feet in length.

The most remarkable of all the effects due to lightning, however, are the extraordinary explosions it causes, and which have been attributed to the sudden vaporization of any moisture contained in the solid materials, such as stone, wood, etc., through which the discharge is passing. The formidable expansive power of steam is well known, and we may therefore conceive that if all the moisture contained in a tree or in a mass of stone were suddenly turned into vapor, the pressure would be such as to burst everything before it.[2] Instances of explosive effects in buildings will be given hereafter. With regard to trees, it is stated that "on the 25th of May, 1842, at the village of Adforton, near Ludlow, lightning struck a poplar tree nearly forty-five feet high; it was shivered to pieces, and the ground for a hundred yards round it was thickly covered with splinters, from four to twelve inches long, many of which seemed to be entirely smashed. The body of the tree was divided into eight or ten large portions, which came away with the branches and fell wide of each other, but all on the South side.[3] This is one example out of many equally remarkable.[4] Still more striking are some of the explosive accidents due to lightning on board ship. On 19th September, 1812, H. M. S. Sultan (of seventy-four guns) was struck by lightning off the coast of Sardinia; "the highest spar, or top-gallant, and royal mast was fairly shaken in pieces; the next, or top-mast, seventy feet long, was burst into shreds like a bundle of laths, and stood gaping open in the upper end; it remained in this condition for some minutes, and then fell with a terrific crash. So complete was the destruction that the decks of the ship were filled with the chips of wreck of more than three tons of wood. The next, or lower mast, weighing eighteen tons, was struck through to the very centre; and the lightning made

[1] "Journal during the Voyage of the Beagle," pp. 43, 44.

[2] Arago's theory as quoted in "The Thunderstorm," p. 122.

[3] "The Thunderstorm," p. 127.

[4] A very similar but not quite so destructive flash is mentioned in "The Electrician" for 27th June of the present year. During a storm at Playford in Suffolk, "a poplar tree, about 300 yards away from the church, was struck by lightning, and the bark was completely stripped away from top to bottom, the Southern half of the body being riven into matchwood. One piece, 5½ lbs. in weight, was picked up 126 yards away from the tree, and the débris covered about two acres of land. The discharge left the tree at the foot, following the direction of a fence for about 15 or 20 feet, threw up a sod about a foot square, and went to earth."

one or two holes in it sufficiently large for a boy to creep into. The chips which were torn out were thrown about the deck. It was with difficulty prevented from falling till the ship got into port, when the mast in its ruined state was taken out. On removing the moldings and fishes it literally fell to pieces."[1]

The length of lightning flashes has been very variously computed, some authorities considering that it may be a mile or even more in length, others that it can never exceed 500 or 700 feet.[2] Probably the truth lies somewhere between these two extremes. At any rate, it seems certain that thunderclouds never attain very high altitudes, probably not over 7,000 feet above the sea-level. On high mountains, thunderclouds are seen below the observer; and thus it would appear that while auroræ are chiefly, if not entirely, confined to the upper strata of the atmosphere, thunderstorms take place in the lower.

The magnetizing power of lightning must not be left unmentioned. After thunderstorms at sea, the action of the ship's compass has often been impaired. Occasionally the polarity of the needle is actually reversed, and often pieces of iron and steel become magnetic through the passage of lightning. Watch-springs have frequently suffered in this way, and after the remarkable storm, during which the church of St. George's, Leicester, was partially destroyed, described in the ensuing chapter, the iron cramps in the steeple and other masses of metal were found to be highly magnetized. These magnetizing effects are taken to indicate that the duration of lightning is, at any rate occasionally, considerably longer than is usually supposed, as magnetization is not momentary, but takes an appreciable time to accomplish.

Thunderstorms are not the only occasions of the manifestation of lightning. Violent volcanic eruptions are always accompanied by this, and sometimes by other electrical phenomena. Lightning seems to have been a specially marked feature of the terrible Krakatoa convulsion, nearly all eye-witnesses of the eruption laying stress upon this, as greatly adding to the horror and magnificence of the spectacle. Thus Captain Woolridge of the *Sir R. Sale*, viewing the volcano from the N. E. at sunset on Sunday evening, 26th May, describes the sky as presenting "a most terrible appearance, the dense mass of clouds being covered with a murky tinge with fierce flashes of lightning. At 7 P. M., when the dense vapor and dust clouds rendered it intensely dark, the whole scene was lighted up from time to time by the electrical discharges, and at one time the cloud above the mountain presented the appearance of an immense pine tree, with the stem and branches formed with volcanic lightning."[3] The same observer,

[1] "The Thunderstorm," p. 130.

[2] See discussion on lightning-rods at the meeting of the British Association, 1888.

[3] "Official Report of the Royal Society on the Eruption of Krakatoa," p. 19.

at a distance of forty miles, speaks of the great vapor cloud looking like "an immense wall, with bursts of forked lightning, at times like huge serpents, rushing through the air." Another observer, whose vessel was situated about forty or fifty English miles N. W. of the volcano, records that "lightning struck the mainmast conductor five or six times," and also that "the mud rain covering the masts, rigging and decks was phosphorescent; the rigging presenting the appearance of St. Elmo's fire."

"This abundant generation of atmospheric electricity," writes Professor Judd, "is a familiar phenomenon in all volcanic eruptions on a grand scale. Steam jets rushing through the orifices of the earth's crust constitute an enormous hydro-electric engine; and the friction of ejected materials striking against one another in their ascent and descent also does much in the way of generating electricity."[1]

CHAPTER VII.

ATMOSPHERIC ELECTRICITY CONTINUED.

DANGERS TO BE APPREHENDED FROM LIGHTNING—MODES OF PROTECTION.

Danger to life and property from lightning—Instances of loss of animal life—Death not inevitable from a "stroke" of lightning—Persons struck do not see the flash—Instance—Globular lightning is seen—Case of Mr. Pitcairn—Injury to buildings—Account of the partial destruction of St. George's Church, Leicester—Dangers formerly encountered at sea during thunderstorms—Examples—Explosion of gunpowder magazines by lightning—Earliest lightning conductors—Their inefficiency—System of protection devised by Sir W. Snow Harris—Directions concerning lightning-rods—Modern modifications—Real use of lightning-rods—Perfect system of protection not yet attained—Necessity of employing experienced electricians to erect lightning-rods—Protection of individuals from lightning—Metal does not "attract" lightning—Theory of an "area of protection" exploded—The most elevated objects not always those struck—Reason.

THE dangers to be apprehended from lightning are, in the case of property, destruction by fire, or by the extraordinary explosive powers sometimes manifested; and in the case of man and the lower animals, severe injury or death, owing to the shock to the nervous system,[2] caused by the passage through a living body of

[1] "Official Report of the Royal Society on the Eruption of Krakatoa," p. 21.

[2] This was until recently the reason assigned for death from lightning, or any

electricity in such large quantities and at such high potential. Timid persons are often ridiculed for the terror they show during thunderstorms. There is, however, something to be said in their defence, for though all storms are not dangerous there is no doubt that some are so in a high degree, and, moreover, the disturbed electrical condition of the atmosphere before and during a heavy storm is of itself sufficient to induce great nervous discomfort in sensitive organizations. Accidents due to lightning are now made so public, owing to the newspapers which flood the civilized world, that they perhaps appear more frequent than they really are; but it is only necessary to remember the large number of thunderstorms which annually take place in the United Kingdom, and the small average of deaths either of men or animals occasioned by them, to feel reassured on this point. Before the introduction and better understanding of lightning-rods, indeed, high isolated buildings, particularly churches, were only too often "struck," and ships also suffered terribly; but in our days such occurrences are comparatively rare, and it is to be hoped that with the further advance of electrical knowledge they will cease altogether.

Before entering on the subject of protection from lightning, it may be interesting to give a few examples of the terrible destruction it may work. First with regard to animal life. In 1858 twenty-five sheep were killed during a thunderstorm near Abingdon.[1] In the same year, at Sacco, in Italy, on the 17th of August, 120 sheep out of a flock of 140 were killed by lightning. The shepherd and the shepherd's boy were not injured, though the latter was carrying a kid in his arms, which was killed.[2] This remarkable escape of human beings, when animals close by them are struck, is not unusual, and would seem to point to the conclusion that the lower animals are more susceptible than man to injuries from lightning. In some instances this could be accounted for by the greater propensity of animals to huddle together in groups, especially when terror-stricken. During thunderstorms such a tendency is dangerous, because the column of heated air rising from their bodies offers a good conducting path to the electric discharge. No such cause, however, could have accounted for the death of the kid in the shepherd boy's arms and the escape of the boy himself. When human beings are struck and recover (for to be struck by lightning by no means necessarily entails death), they invariably say they did not see the flash which rendered them unconscious. Many instances of this are cited in "The Thunderstorm," to which work frequent reference has already been made. A relative of the

powerful electric "shock." It appears, however, according to the latest investigations, that some direct effect is produced upon the heart, and that is most likely the immediate cause of death.

[1] "The Thunderstorm," p. 163. [2] *Ibid.*, p. 163.

present writer, who was struck by a flash of lightning during a violent thunderstorm in Yorkshire in 1886, saw nothing, neither did his wife, who was close to him and suffered, though slightly in comparison, from the effects of the same flash. More curiously, the woman in whose farm-house they had taken temporary refuge, and who was in another room, saw no flash either at this moment, but heard a sudden, sharp explosion, which she took for the report of a gun, and rushed in a state of great anger to demand an explanation from her guests, when, to her astonishment, she found one of them in an unconscious and apparently dying state. A short time sufficed to restore his senses, and no other injury was sustained beyond a shock to the nervous system, which for a time affected the general health and spirits, but not in any serious or incapacitating manner.[1] Globular lightning, whose movements are so much slower, is not thus invisible to those whom it injures. M. Planté cites an instance of a ball of fire the size of a fist, which, during a violent thunderstorm, appeared to two clergymen, Messrs. Wainhouse and Pitcairn, who were together in a room in the rectory of Steeple-Ashton, Wiltshire. It seemed to be one foot distant from them, and about the height of a man from the ground, and was surrounded by a dark smoke. Its explosion was attended by a noise comparable to the firing of several cannons and a strong "sulphurous" smell filled the house immediately afterward. Mr. Pitcairn was dangerously wounded.[2]

With regard to buildings, churches and any high or isolated erections are most exposed to danger from lightning. Mr. Tomlinson gives a formidable list of damages in "The Thunderstorm," occurring between the years 1822 and 1858, in which no fewer than thirty-three churches are included, and enters into many interesting details with regard to several of them. The most striking account is that of the injuries sustained by St. George's Church, Leicester, on 1st August, 1846, during a storm of quite exceptional violence and duration, and in which the phenomenon of globular lightning repeatedly presented itself. The storm had already been raging for hours, accompanied by

[1] One of the curious tree-like marks which have often been noticed on the bodies of persons struck by lightning was produced in this instance, and remained for a considerable time. It extended over the lower ribs on the right side, and resembled the trunks of two trees close together, with branches ramifying from them. The sufferer on this occasion also said that though he did not see the lightning he heard the thunder; in fact, it was the last thing he remembered before losing consciousness.

[2] "Phénomènes électriques de l'Atmosphère," p. 221. In a previous portion of this work M. Planté justly remarks "that it is not a small mass of air rarified and rendered luminous by the passage of an electric current which could thus explode with the noise of thunder and resolve itself into 'strokes' of lightning. The source of this final phenomenon is in the reservoir of electricity contained in the thundercloud, which discharges itself at the point where the first escape began in the form of a ball of fire," p. 50.

torrents of rain, when "at five minutes past eight, after one or two peals of unusual distinctness, the Church of St. George was struck with a report resembling the discharge of cannon, and with a concussion of the air which shook the neighboring houses and extinguished a lamp burning at the entrance of the news-room, many hundred feet distant. . . . Two of the spectators of this awful event were Captain Jackson and the Rev. R. Burnaby, rector of the parish, who both described the flash as a vivid stream of light, followed by a red and globular mass of fire, and darting obliquely from the North-west with immense velocity against the upper part of the spire. For the distance of 40 feet on the eastern side and nearly 70 on the west, the massive stonework of the spire was instantly rent asunder and laid in ruins. Large blocks of stone were hurled in all directions, broken into small fragments, and in some cases, as there is every reason to believe, reduced to powder. One fragment of considerable size was hurled against the window of a house 300 feet distant, shattering to pieces the woodwork, as well as fourteen out of the sixteen panes of glass. . . . It has been computed that a hundred tons of stone were on this occasion blown to a distance of 30 feet in three seconds. In addition to the shivering of the spire, the pinnacles at the angles of the tower were all more or less damaged, the flying buttresses cracked through and violently shaken, many of the open battlements at the base of the spire knocked away, the roof of the church completely riddled, the roofs of the side entrances destroyed, and the stone staircases of the gallery shattered. The top of the spire, when left without support beneath, fell perpendicularly downwards inside the steeple, causing much devastation in its descent."[1]

The scene of this fearful accident[2] was afterwards minutely examined, when it became evident that the formidable explosions which worked the destruction were caused by the electric discharge on its road to the earth, bursting its way from one good conducting point to another through masses of badly conducting material. Thus we are told that "after traversing the vane and spindle, and the terminating iron supports, the only path left for the fluid was through a series of iron cramps, *separated by means of sand-stone; and here it was that the explosion commenced*, the stone being torn and hurled aside as it came in the path of the lightning to the lowest lead lights of the spire."[3]

[1] "The Thunderstorm," p. 153 ff.

[2] One almost equally severe appears to have occurred at Louvain on April 8 of the present year, 1890. The cathedral was struck by lightning. "One of the turrets was completely destroyed, and the top, weighing about four tons, was projected a distance of twenty-two yards, demolishing a house, while blocks of stone weighing from two to three tons were hurled a distance of nearly seventy yards, damaging the houses in the neighborhood."—*The Electrician* for June 6, 1890, p. 109.

[3] "The Thunderstorm," p. 156. Apparently this church was unprotected by any lightning conductors whatever.

In this accident, terrible as it was, no life was sacrificed, but M. Planté cites an account of a violent storm which took place on the 27th of July, 1769, during which several hundred persons, being congregated in a large public hall, suddenly saw a fiery globe the size of a large cannon-ball appear through an opening in the roof. All the lights immediately went out, and more than seventy-six persons were killed or wounded.[1]

However fearful the destruction worked by lightning inland may sometimes have been, ships were formerly exposed to a far greater degree of danger from this source. Isolated objects on the vast plain of the ocean, it was almost impossible that during thunder-storms they could escape being made part of the path of an electric discharge between the clouds and the sea, and the wonder is rather that so many escaped than that so many were "struck." Neverthleless, the destruction both of life and property before Sir William Snow Harris devised an efficient system of protection, was truly appalling. The accidents to H.M. ships alone between the years 1790 and 1840 numbered 280, some exceedingly serious; and the loss of life was proportionately great, 100 seamen having been killed, and 250 dangerously injured, while the monetary loss to the country was reckoned at £150,000.[2] Space forbids the citation of more than one instance, that of the Repulse, a 74-gun ship. On the 13th of April, 1810, the Repulse, being off the coast of Spain, was overtaken by "a heavy squall of wind, with rain, thunder and lightning, at which time the people were employed in getting down their washed clothes which hung from the rigging, when the ship was struck by two vivid flashes of lightning which shivered the maintop-gallant mast, and severely damaged the main-mast. Seven men were killed on the spot, three others only survived a few days, and ten were maimed for life. After the second discharge the rain fell in torrents; the ship was more completely crippled than if she had been in action, and the squadron, then engaged on a critical service, lost for a time one of its fastest and best ships."[3]

More terrible yet is the description of accidents which occur when lightning sets a ship on fire. Fearful stories of suffering and privation have thus been added to the roll of disasters at sea. Among others the case of the Tanjore, a ship belonging to the East India Company, is cited by Mr. Tomlinson. In May, 1820, she was struck by lightning forty miles off the coast of Ceylon; two men were instantly killed, and many others rendered insensible; the cargo, which was partly of brandy, caught fire, and burned so fiercely that the crew and passengers had to hurry into the boats without waiting even to take food and water. Fortunately a few hours afterwards they met with a native vessel and so were rescued.[4]

[1] "Phénomènes électriques de l'Atmosphére," p. 222.
[2] "The Thunderstorm," p. 171. [3] *Ibid*, p. 172. [4] *Ibid*. p. 182.

Many instances have occurred of powder magazines being struck and exploded by lightning. "In 1855, on the 7th of October, about 2 P. M., a firework manufactory in Green Street, Liverpool, was struck by lightning and blown up; the factory and the adjoining houses were destroyed, and many persons severely injured. . . . On the 10th of August, 1857, about midnight, lightning fell on the magazine of Joudpore, in the Bombay Presidency, whereby some thousands of maunds of gunpowder were blown up. Five hundred houses were destroyed, and nearly one thousand persons are reported to have been killed."[1]

Enough examples have now been quoted to show the need of protection from lightning, and it is time to turn our attention to the means employed for attaining this end. Lightning conductors were an almost immediate consequence of Franklin's famous experiment in 1752 (described on p. 33 of the present work), and only ten years later the first erected in England was put up by Dr. Watson at Paynsted. It is amusing to think that so little was the principle of their action understood, that during the war of Independence an animated discussion was carried on between the supporters of pointed lightning rods and those who recommended rounded tops. The matter was made a political question, the pointed rods being in favor with Franklin and the Revolutionary party, and the blunt with "loyal subjects and good citizens;"[2] neither side considering the scientific and practical question as to which was in reality the best protector, worth attending to. As a matter of fact, the pointed rods were, of course, preferable, points contributing to a silent and noiseless discharge, and round tops, on the contrary, being likely to cause an explosive discharge between the conductor and the cloud. In these early days, however, many other important matters beside that of points were but ill understood. One lightning rod stuck up anywhere, perhaps insulated at the bottom, instead of having a good earth connection, or run into a small stone tank of water, or into any other equally impossible place according to the better-instructed ideas of the present day, was deemed sufficient. Ships also were provided with a chain conductor of very small dimensions, stowed away in a box, and taken out to be suspended from the masts if occasion required. It is not surprising that such protection as this was found terribly inadequate, and that great danger was incurred by the sailors, through having to place these conductors in position during a storm. To Sir William Snow Harris belongs the honor of having first devised a really adequate system of protection both for buildings and ships. He insisted upon an unbroken line of metallic connection between every part of the building or vessel and the lightning rods as indispensable. Isolated masses of metal forming an

[1] "The Thunderstorm," p. 169.

[2] *Ibid.*, p. 223, note.

integral part of any erection are fraught with danger, and exceedingly likely to cause such destructive explosions as those which occurred in the case of St. George's Church, Leicester, cited above—for the lightning in leaping from one conducting point to another will shatter the badly-conducting substances obstructing its path. The upright rod or rods should be armed with one or more points, and should project above those portions of the building to which they are attached. They should also have a thoroughly good earth connection, *i. e.*, the earth about them should be kept damp, and they should not be buried in charcoal, or beds of stone or rubble, nor led into inclosed tanks.[1] Running water, on the contrary, is excellent, as it affords a thoroughly good conducting channel for the electric discharge.

Lightning rods should also have a good extent of surface, but they need not, as was formerly thought, be solid. Hollow rods are quite as good, and flat ribbons, or a bundle of separate strands of thickish wire, better still. The solid rods were used under the idea that they offered a greater amount of conducting material to the passage of the electric discharge, because currents of electricity (and a discharge is a momentary current) penetrate the substance of conductors, and do not remain on the surface like static charges; but this only holds good of steady currents, not of sudden rushes of electricity like the discharge of a Leyden jar and lightning. In these cases the velocity is so great and the duration so short that the electricity scarcely penetrates below the surface, and therefore the important matter is that the latter should be of sufficient extent, not that the conductor should be solid. A modification has also arisen in the views held as to the best metal to employ in the construction of lightning rods. Until recently, copper was recommended by all electricians on account of its high conducting power, but it appears now that for this very reason it may be less suitable than iron, because, as Dr. Oliver Lodge stated in a lecture delivered before the Society of Arts on March 17, 1888, "If a great weight or a large reservoir of water were propped up above one's house, one would not say that, the safe thing being to get it down as quickly as possible, it was advisable to break away the props, or to blow the bottom out of the reservoir; no, one would prefer to let it slide slowly and gradually down a well-resisting channel, so as to disperse the energy gradually."

These words "to disperse the energy gradually" recall a consideration of the highest importance, which must never be lost sight of in any system of protection from lightning. The question at issue is not only—or even mainly—how to conduct a certain quantity of electricity safely and quietly into the earth, but how to dispose of the

[1] It is specially recommended also that they should be buried deeply in the earth, not too near the surface.

enormous energy developed by lightning, which can neither be ignored nor conjured out of existence. Therefore, a certain amount of resistance may be a good thing as affording work to do to overcome it; but it need hardly be said that it should never be sufficient to occasion great heating, as that at once entails the danger of fire, or the collapse of the conductor through fusion, either throughout its length, or at special points, such as the joints, where increase of resistance is encountered.

Even with every precaution taken, and a system of protection from lightning adopted in accordance with the best practical electrical experience of the day, absolute safety cannot be guaranteed, as was abundantly proved by the Hotel de Ville at Brussels, which is protected by a most elaborate and carefully carried out system of lightning conductors, having been struck by lightning, and a portion set on fire in the month of June, 1888. But little damage was done, as the fire was almost immediately extinguished. Nevertheless, the case is a most important and instructive one, showing, as it does, that protection from lightning, though vastly improved, is not even yet perfectly understood. One of our leading electricians distinguishes between two main cases of lightning flash, the one caused by a steadily increasing strain between a cloud and the earth, so that the path of the flash is inductively prepared beforehand; the other by a sudden rise of potential in a cloud, between which and the earth no strain previously existed, by the discharge of another cloud into it, so that an "impulsive rush" of electricity takes place to the earth without any previous preparation. He considers that in the first of these cases, a system of protection carried out according to present ideas would be efficient, but not in the second case, and his conclusions are based upon a number of interesting and highly instructive original experiments.[1]

The foregoing remarks, though giving the merest outline of the subject, may nevertheless enable the general reader to understand something of its importance, and will at any rate serve to show him that the protection of a building from lightning cannot possibly be properly accomplished by any but practical electricians. A village workman must not be depended on for the erection of lightning-rods. It may perhaps be of interest to mention that in the case of gunpowder magazines and other stores of explosive material, high pointed conductors are not recommended. It must always be remembered that owing to the facilities they offer, they are likely, if present in sufficient numbers and at a sufficient altitude, to determine

[1] See Mann Lectures before the Society of Arts by Dr. Oliver Lodge, F. R. S., in March, 1888; also a paper by the same author on "Lightning, Lightning Conductors, and Lightning Protectors," read before the Institution of Electrical Engineers in April, 1889, reported in *The Electrician* of 3d May, 1889.

a discharge, which might not otherwise take place, between a cloud and the earth; and though in ordinary cases this would not be a source of danger, it certainly would where gunpowder or other explosive substances are concerned, as the smallest side spark (such as frequently takes place from lightning-rods to other conductors in close proximity) might cause a terrible accident. A network of iron entirely covering the edifice, or, better still, making the erection itself of iron, is far preferable in such cases.[1]

With respect to the protection of individuals from lightning, a few plain directions may be given. It is a well-known source of danger to stand close under trees or under any high and isolated object. Detached pieces of metal worn about the person should also be avoided, as well as standing near a fireplace if there is a fire burning. It is of no use to cover oneself with silk garments, or in fact to attempt insulation in any way, as this only increases danger. On the other hand, the rather impossible protection of a suit of armor would render its wearer perfectly safe so long as the joints did not become overheated, which might perhaps occur if the armor were actually struck. Such a defence, however, though excellent for the owner, would be exceedingly dangerous to his friends, for to touch it during the progress of a storm would ensure a violent, possibly fatal shock; and the same remark applies to iron network over houses and other erections. The building thus enclosed and all its inmates would be perfectly safe, but any one approaching it from the outside during a storm, and laying his hand upon the metal, would certainly rue the consequences.

It must not be supposed, however, that there is anything in metal which attracts lightning. Such is not the case. On account of its high conducting power it offers an easy path to the electric discharge, of which the latter will, if possible, avail itself; but it will not go out of its way to pick out a lightning-rod or any other metallic conductor. Instances have occurred of lightning striking buildings in close

[1] Telegraphic and telephonic instruments and stations require special protection from lightning, and the guards with which they are provided are almost always constructed on the principle that owing to the "impedance" offered by good conductors to a sudden flash (due to the oscillatory nature of the latter) it would rather jump over a short air-space than follow a length of wire. Double combs are used as protectors in telephone exchanges; a pair of plates separated by a very short space in telegraphic offices. These do not always prove efficient, however, and Dr. Oliver Lodge has devised a new lightning guard, for which he claims almost absolute perfection, and whose principle, in his own words, consists in taking "the overflow from one protector and giving it the chance of another; then taking the overflow from this and offering it another air-gap, and so on till nothing is left; at the same time diminishing the overflow from each protector as much as possible by the use of self-induction coils, which impede the violently varying or alternating rushes by their electro-magnetic inertia."—Quoted from a paper read before the Institution of Electrical Engineers on 24th April, 1890, published in *The Electrician* for 23d May.

proximity to lightning-rods, erected under the idea that they would afford an "area of protection," within the limits of which nothing but themselves could be struck. This erroneous theory of an "area of protection" is fast dying out, as also that of the most elevated objects being always the ones struck. Very many instances are on record of houses in the immediate neighorhood of tall trees suffering from lightning, while the trees themselves escaped; and this, though apparently surprising at first, ceases to be so when we remember that the state of strain to which all the phenomena of discharge are due does not exist primarily between a cloud and the lightning-rod, tree, or steeple, or whatever the elevated object may be, but between the cloud and the whole of that portion of the earth's surface lying beneath it; therefore, all that these isolated and, in comparison to the extent of surface, small elevations can do, if they are good conductors, is to protect themselves from danger by rendering that part of the discharge which is taking place between them and the cloud harmless. They cannot do more than this, and hence the paramount importance of a metallic connection between every part of the building to be protected and its lightning-rods. During the discussion on lightning-rods which took place between Sections A and G, at the meeting of the British Association in Bath, 1888, a most remarkable photograph of a flash which occurred during a storm in America was shown. It can only be described by saying that the sky seemed to be literally pouring down the electric fire on every side, and the remark was justly made by its exhibitor,[1] "Where in such a case could the 'area of protection' be?" The only real safety would lie in the whole surface upon which this enormous quantity of electricity was descending being of good conducting matter; and in the presence of such tremendous manifestations of natural energy as this, we can but feel that though it behooves us to take every precaution which the most advanced science recommends, our preservation depends on a Higher Power and a Vaster Knowledge than any which our resources can command.

[1] The Hon. Ralph Abercrombie, F.R.S.

MAGNETISM

PART II.

CHAPTER I.

GENERAL PROPERTIES OF MAGNETS.

Ancient knowledge of natural magnets—Lodestone an ore of iron—Made useful in navigation in the twelfth century—Gilbert's discovery of magnetic poles—Attraction between unlike and repulsion between like magnetic poles—The earth a magnet—Naming of the poles—Magnetic substances—Dia-magnetic substances—Action and re-action between magnets and magnetic substances equal—Similarities and dissimilarities between electric and magnetic induction—Magnetic induction cannot take place across magnetic substances—Acts across a vacuum—Various ways of making magnets—Consequent poles—Bar and horse-shoe magnets—Magnetic shell—Strength and lifting-power of magnet—Causes of loss of magnetization—Sub-division of magnets—Molecular theory of magnetism.

NATURAL magnets were known from very ancient times, and their name is derived from Magnesia, in Asia Minor, where many of the hard black stones possessing the property of attracting iron and steel were found. The English name of lodestone means simply leading stone. It is an ore of iron, called by mineralogists *magnetite*, and exists in large quantities in Sweden, Spain, and various other countries; though it by no means always possesses magnetic properties, being often found entirely destitute of them; nor is it known by what means they are acquired by those specimens of the ore which exhibit them. About the twelfth century it became known in Europe that lodestones, whose power of attracting iron was already attributed to magic, possessed another yet more marvelous peculiarity, viz., that of setting themselves always in a North and South direction when freely suspended. This property was made useful in navigation; and in fact the name lodestone is derived from the fact of the magnet stones being able to act as mariners' guides. The first artificial magnets were made by rubbing iron or steel with lodestone, when it was found that the latter imparted its magnetic properties to these substances—the iron, however, only retaining its magnetism for a very short time; whereas the steel, though not able to be so powerfully magnetized as iron, did not again lose the properties it had acquired, but became a permanent magnet. Other ways of making artificial magnets, which will be mentioned in due course, are now known and extensively used.

Dr. Gilbert, whose electrical discoveries have already been mentioned, made many of equal importance respecting magnets, and in his work "De Magnete" described a number of elementary facts regarding them. He was the first to notice that the attractive power appears to reside at the two ends of a magnet, called always its *poles*.[1] This fact can easily be proved by placing an ordinary bar magnet among a number of iron filings, which will be seen to arrange themselves in thick tufts round the poles, thinning as the centre is approached, while at the actual centre there are none. This non-attractive part of the magnet Gilbert named the *equator*, and the imaginary line joining the poles, the *axis*.

It has already been mentioned that a freely-suspended magnet sets itself in a particular direction with regard to the earth, viz., with one pole pointing nearly North, and the other nearly South; moreover, it is always the *same* pole which points in the *same* direction; for if a magnet be turned by any means out of its natural position with regard to the earth, it will return to it again the moment the constraining force ceases, the pole which was before pointing North resuming the same direction. Let it now be supposed that there are two magnets the North-seeking poles of which have both been marked. One of these magnets is freely suspended (or balanced upon a pivot, which comes to the same thing), the other being held in the hand. The free magnet will, of course, be turned into its usual North and South direction; and this being so, let its North-seeking pole be approached to the North-seeking pole of the second magnet, when it will be seen that the former is instantly turned away from the latter, thus showing that *two North-seeking poles repel each other*.

Let us now vary the experiment by approaching the South-seeking pole of the magnet held in the hand to the North-seeking pole of the free magnet. We shall find that the latter will turn *toward* the South-seeking pole, and, if near enough, will rush into contact with it, thus remaining till the two are separated by force, showing that a *North-seeking and a South-seeking pole attract each other*.

It would appear, therefore, that as there are two kinds of electricity, positive and negative, so there are two kinds of magnetism, North-seeking and South-seeking. Moreover, since it is evident from the

[1] It is only in a long, thin bar magnet that the poles are actually situated at the extreme ends, however. In thicker magnets they lie slightly nearer the centre.

position taken up by a magnet with regard to the earth that the North part of the latter attracts one pole of the magnet and the South part the other, and since only magnets have this power of attraction and repulsion over other magnets, we are driven to the conclusion that the earth itself must be a magnet obeying the invariable law that *like poles repel and unlike poles attract each other*, and that this is the reason of the North and South direction taken up by a freely suspended magnet, whose North-seeking pole points to the South magnetic pole of the earth, and its South-seeking pole to the earth's North magnetic pole. It is usual and more convenient to employ, instead of a magnet, a magnetic needle for experimental purposes. The needle is made of steel and is very light and thin, usually lozenge-shaped, and balanced on a pivot in the manner of that used in the ordinary pocket compass. It is magnetized by being rubbed with a magnet; and has, of course, a North-seeking and South-seeking pole. These are in common parlance called the North and South Poles, at least in England; but the custom leads to very great confusion of ideas; for if we name that pole of the magnetic needle pointing toward the North magnetic pole of the earth the North Pole, and that pointing toward the South magnetic pole the South Pole, we virtually state that like poles attract each other, which is the very reverse of the fact, and consequently the terms North-*seeking* and South-*seeking* which have frequently been adopted by English men of science are far more correct, and will be used in the present work.

A magnet always has two poles, one North-seeking and one South-seeking; it is quite impossible to obtain a magnet with one pole only; but a *magnetic substance*, viz., a substance which, like iron, has the power of attracting and being attracted by a magnet, has no poles, neither does it appear to have any force of repulsion, for it is equally drawn to either pole of the magnet which may be presented to it. Iron and steel are not the only magnetic substances; nickel and cobalt show the same properties, but in a very inferior degree; and some other metals, as well as paper, porcelain, and oxygen gas, are feebly attracted if exposed to the influence of a very powerful magnet.

It was for a long time supposed that those substances not attracted by a magnet were not influenced by it at all; but experiment has proved that if subjected to strong magnetic action they are repelled, or at least appear to be so. Bismuth possesses this property in the most marked degree, and a small bar of bismuth suspended between the poles of two powerful magnets,[1] turns itself so as to lie at right angles to the line between the poles, thus getting as far away from them as possible.[2] A bar of iron or steel suspended in the same

[1] Electro-magnets, which will be described in a future chapter, are employed in these experiments.

[2] This behavior of the bismuth and of other dia-magnetic substances has, however,

manner would, on the contrary, turn along this line so as to present its ends to the poles, thus approaching them as closely as it could. Substances which appear to be repelled by magnets are called *dia-magnetic.*[1]

By *magnetic force* is meant the force with which a magnet attracts or repels another magnet, or with which it attracts a piece of iron, or of any magnetic substance. This force decreases with distance, and between two magnet poles it is directly proportional to their strength, and, if they are very small and far apart, inversely proportional to the square of the distance between them.

It is easily understood that the attraction between two unlike magnet poles is mutual. Each is drawn toward the other; but perhaps it is not quite so evident that the attraction between a magnet and a magnetic substance, a lump of iron for instance, is also mutual. At any rate, the popular idea is that the magnet attracts the iron, but we do not hear of the iron attracting the magnet. Yet this is equally true; for if a magnet be balanced on a piece of cork and set floating in a basin of water, and a lump of iron be held near the edge of the basin, the magnet will immediately move toward it, just as we should see the iron move toward the magnet if their positions were reversed. Moreover, the action and reaction between a magnet and a magnetic substance are equal, just as the action and reaction between two magnets are equal. The fact is that a magnetic substance is one in which a magnet can induce temporary or permanent magnetism of the opposite kind to that of the pole presented to it, and this is the cause of the mutual attraction.

Magnetic induction can only take place in magnetic substances, just as electric induction can only take place in conductors; and here we may remark on the great likeness existing between some of the fundamental phenomena of electricity and magnetism. Electrified bodies can attract and can repel; so can magnets. Electrified bodies can induce electricity in other bodies; magnets in like manner can induce magnetism. Yet, though there are great similarities, there are also great differences. An electrified body has no poles; its power of attraction and repulsion resides all over its surface. Moreover, an electrified body electrifying another by contact, electrifies it in the same way as itself, and parts with some of its own original charge to do so. A magnet behaves quite differently; its poles always magnetize in the opposite way to their own magnetism, whether by contact or by influence, and no magnet ever loses any of its magnetism

been shown to be due, not to their being really repelled, but urged into the weakest part of the magnetic field. Substances which are faintly magnetic behave as though they were dia-magnetic if immersed in a medium more magnetic than themselves.

[1] Thus named because they allow the magnetic forces to act across them, which "magnetic" or, as they are often called, "para-magnetic" substances will not do.

by imparting it to another body. It remains quite as powerful after as before the operation. Neither can it be said that magnetism and stationary electric charges show the slightest relationship to one another,[1] though, as we shall hereafter see, electric *currents* and magnetism appear to be very closely connected, indeed; and since current and static electricity have been proved to be the same agent manifesting itself under different conditions, we may justly infer that magnetism is not of a wholly different nature from either.

Magnetic induction will take place through any substance, provided it be not itself magnetic. A magnet enclosed in glass or wood, or immersed in water, will equally exert its power of attraction and repulsion. But it cannot do this across thick iron, and a magnet placed within a thick hollow iron ball is incapable of influencing or being influenced by any outside magnet. The reason of this would appear to be that the action and reaction between the magnet and the iron employ the whole magnetic force of both, and therefore none can penetrate beyond the iron. Magnetic induction can take place across a vacuum, thus showing that the presence of ordinary matter is not necessary to the transmission of the magnetic forces, and that the real medium by which they are conveyed is the ether.

As has already been stated, there are various ways of making magnets. The simplest, but not the best, is by stroking the bar or needle of steel to be magnetized from end to end with a lodestone or steel magnet. This is called magnetization by single touch. Another and better way is to use two magnets, commencing by placing their opposite poles together in the centre of the bar to be magnetized (which is laid in a horizontal position), and then drawing them along to the ends, repeating the operation several times over. This is called magnetization by divided touch. *Both* sides of the bar should be subjected to the same treatment, and care taken that it is methodically and regularly followed out; otherwise there may be points between the true poles where other poles will be formed, called *consequent poles*, thus weakening the external influence of the magnet through the reaction of the consequent poles on each other. Magnets can be made by the action of the earth's magnetism on bars of steel held in the magnetic meridian, *i. e.*, with one end directed towards the magnetic North, and the other toward the magnetic South Pole of the earth, and struck by a wooden mallet while in this position. A bar of steel raised to a red heat, and allowed to cool while lying in the magnetic meridian, also acquires magnetic properties; but by far the most powerful magnets are made by placing a bar of steel or iron inside a coil of wire through which an electric current is caused to pass. The steel is made into a permanent magnet by this operation,

[1] It appears that if a magnet and a charged body are in relative motion, a very slight inter-action occurs, tending to make them revolve round each other.

but the soft iron only retains the whole of its magnetic properties while the current is passing. During this time, however, it becomes magnetized to a very high degree, indeed; and these electro-magnets, as they are called, are by far the most powerful of any, and will be described and explained in a later chapter. Magnets which have been magnetized to the highest degree of which they are capable, are said to be *saturated.*

A magnet can be made of any shape, but the bar and and the horse-shoe are the most common. Instead of a bar a bundle of steel wires may be magnetized, and will act as one magnet. These *laminated magnets* are stronger than single bars, provided the wires be magnetized separately before being put together. A thin sheet of metal may be so magnetized that the whole of one face of it will possess North-seeking, and the whole of the opposite face South-seeking magnetism. Such an arrangement is called a magnetic shell, and is of considerable interest and importance, because it in many respects greatly resembles a closed voltaic circuit.

By the *strength* of a magnet is meant the amount of magnetic force it possesses, *i. e.*, the power of attraction and repulsion shown by its poles; but the *lifting power* of a magnet is a different thing. It signifies the weight which a magnet is able to support, and that depends on the surfaces of contact as well as on the strength of the magnet. A horse-shoe magnet has much more lifting power than a bar magnet, for the simple reason that both its poles are pressed into the service, whereas with a bar magnet one only can be employed for this purpose.

Though steel once magnetized becomes so permanently, as we have seen, there are, nevertheless, circumstances under which it cannot retain its magnetic properties. They are weakened if the steel is very much heated, though partially recovered as it cools, and lost altogether if it is made red hot. If the ordinary temperature of a steel magnet is lowered, on the contrary, its strength increases, unless the cold to which it is subjected be very extreme, indeed, when it loses its magnetization.[1] The same thing happens if it is roughly used and knocked about; and this seems to point to the conclusion that magnetism is closely connected with molecular structure. A far more convincing testimony is borne to this theory, however, by the effect of rupture on a magnet. The latter appears, as has been stated, to have no magnetic force at its centre. Nevertheless, if a magnet is broken in half, each half will be a perfect magnet with a North-seeking and a South-seeking pole; and if the halves be broken in their turn, four perfect magnets will have taken the place of the single original one. In fact, the process may be repeated indefinitely; and if the single magnet were to

[1] Professor Silvanus Thompson states that a steel magnet brought down to a temperature of 100° C. below zero loses its magnetic properties.—"Elementary Lessons in Electricity and Magnetism," p. 84.

be broken a hundred or a thousand times, each piece, however small, would still be a perfect magnet.

Only one theory has been put forward which seems to give a satisfactory explanation of this phenomenon. This is, that every molecule contained in a magnet is itself an infinitesimal magnet with a North-seeking and a South-seeking pole, and that the state of magnetization consists in all the molecules being turned the same way—set end to end as it were—so that the North-seeking poles all point in one direction, and the South-seeking poles in the opposite direction. The inevitable result of such an arrangement would be, that the magnetic force would always appear to lie at the ends of the magnet, and yet that it could be divided into any number of perfect magnets.

There are other phenomena besides those already mentioned which

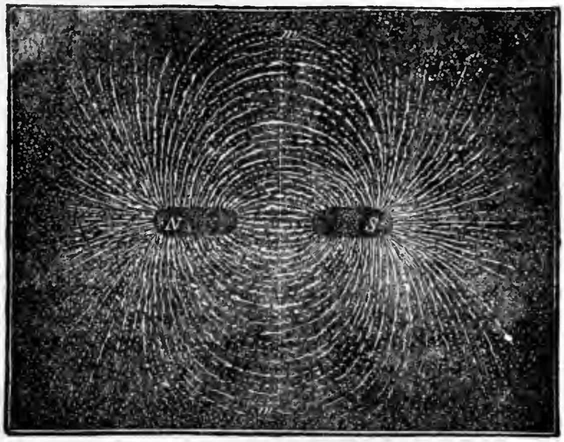

FIG. 11.—Lines of force in a magnetic field formed by a single bar magnet.

support the molecular theory of magnetization. A bar of steel when magnetized slightly lengthens, thus showing that there is a change of arrangement in the molecules, and that it must be one which places them parallel to each other. Water rendered muddy by being mixed with fine magnetic oxide of iron becomes, when magnetized, clearer in the direction of magnetization, as though light were able to pass better by reason of the parallel arrangement. A metallic clink is also heard when iron is magnetized and demagnetized, and when this is rapidly done it becomes hot, showing that internal friction must take place.[1]

[1] Since the above was written, Professor Ewing has given, in a paper on magnetic induction, communicated to section A at the meeting of the British Association, at Leeds, 1890, an account of some highly interesting and important experiments, which appear to place the molecular theory of magnetization on a much firmer basis than has ever been the case before. It may, in fact, be said to be to a great extent proved.

The space all round a magnet, within which the magnetic forces make themselves felt, is called a *magnetic field*, and the directions along which these forces act have been called *lines of force*. Their shapes differ according to the number, position and shape of the magnets forming the field.

Figures of these lines of force are obtained by placing a sheet of paper over a magnet, and then sifting very fine iron filings through a muslin bag over the paper. They arrange themselves in beautiful curving lines, each particle taking up the position assigned to it by the combined action of both poles, so that at every point of the lines the resultant direction of the attractive and repulsive forces is accurately shown. Fig. 11 gives the curves of the lines of force in a magnetic field formed by a single bar magnet; Fig. 12 shows those

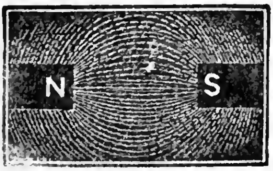

FIG. 12.—Lines of force in a magnetic field formed by two bar magnets, with North-seeking and South-seeking poles confronting each other.

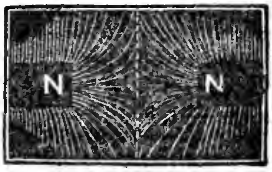

FIG. 13.—Lines of force in a magnetic field formed by two bar magnets, with North-seeking poles confronting each other.

in a field containing two bar magnets with opposite poles confronting each other; Fig. 13 those where similar poles confront each other. These two last figures illustrate most strikingly the action of the attractive and repulsive forces. The lines from the opposite poles which attract each other, curve inward so as to enter the one pole from the other; the lines from the similar poles which repel each other curve outward, turning aside at right angles so as to get as far away as possible.

The size and strength of a magnetic field depend on the strength of the magnet or magnets contained in it, and on their position with regard to each other. The strength is always greatest near the poles. Any magnetic substance placed in the field becomes for the time magnetized by induction.

CHAPTER II.

MAGNETISM OF THE EARTH.

Gilbert discoverer of the earth's magnetism—Oscillations of magnetic needle before settling itself in the magnetic meridian—Magnetic intensity—Magnetic poles of the earth—Declination of the needle—Variations in the declination and their causes—Line of no variation—Isogonic lines—Inclination of the needle—Inclination compass—Magnetic equator—Isoclinic lines—Magnetic maps—Fluctuations in the earth's magnetism—Periodicity in the occurrence of magnetic storms—Influence of the sun on terrestrial magnetism—Effect of the earth's magnetic force on the magnetic needle, directive only—Magnetization of steel and iron objects by the earth—Magnetism of iron ships.

THE honor of first discovering that the earth itself is a large magnet belongs to the same Dr. Gilbert whose name has already been several times mentioned. As we have seen, a magnet or magnetic needle when freely suspended, *i. e.*, hung from, or balanced on the point, which is its centre of gravity, takes up a particular position with regard to the earth, turning itself so as to lie in the magnetic meridian. It does not do this with one steady movement, but undergoes a series of oscillations before finally reaching its position of equilibrium, and every time it is moved or disturbed the oscillations are repeated. By making calculations on the number which occur in one minute, the strength of the earth's magnetism, called its *magnetic force* or *intensity*, at the particular locality can be discovered ; though it must be remembered that the weight, shape and length of the magnet have to be taken into account, the number of oscillations executed in a minute depending on them as well as on the strength of the earth's magnetism.

From the fact that the magnetic needle does not point due North and South, we may infer what is in fact actually known, that the earth's magnetic poles do not coincide with its geographical poles. The North magnetic pole is situated just within the Arctic Circle in Lat. 70° 5′ N., Long. 96° 46′ W. The South magnetic pole has never been discovered, and from various indications it is thought that there may be two. The angle made by the magnetic needle with the geographical meridian is called its *declination*, and this is continually varying. The North-seeking pole lies at present to the West in Europe and Africa, and to the East in Asia and the greater part of North and South America. Some of the variations in the declination of the needle take place gradually through a number of years, some annually and daily,[1] and some are the result of sudden electric and magnetic disturbances, such as displays of the Aurora Borealis,

[1] The daily variations follow the course of the sun, or, rather, seem to make an effort to do so, for they are very slight.

earthquakes and volcanic eruptions. Thunderstorms and ordinary atmospheric perturbations produce no such effect, however. These accidental variations in the declination of the needle are known as magnetic storms, and are sometimes very marked indeed. Magnetic storms are always attended by a display of the Aurora Borealis in Northern latitudes, and are sometimes simultaneous at widely distant places on the earth's surface.

There are certain parts of the earth where the magnetic North and South do actually coincide with the geographical North and South, and at these places there is no declination of the magnetic needle. They are connected by an imaginary line called a line of no declination, or *agonic line*, which passes round the earth, nearly from North to South, cutting the Equator at right angles. Besides the agonic line there are a number of other imaginary lines called *isogonic lines*. Each one of these connects places on the earth's surface where the declination is the same. A map drawn out representing the isogonic lines is called a declination map,[1] and is of great service to mariners, whose compass is in like manner called a declination compass. It is not known who was the first inventor of this valuable instrument, but it was in general use in Europe in the thirteenth century, though in a much more primitive form than any with which we are familiar. It consisted merely of a magnetic needle set floating in a basin of water by means of a cork or of two straws, and nothing then was understood about "declination;" the needle was supposed to point due North and South.[2] Hundreds of years before the compass was used in Europe, it was known to the Chinese, who navigated their ships by means of a magnetic needle pointing South, and it is even stated by Humboldt that 1000 years B. C. the Chinese had magnetic carriages in which to find their way across the plains of Tartary. The compass consisted of the figure of a man with a movable arm pointing to the South.

Beside setting itself in the magnetic meridian, there is another peculiarity to be remarked in a freely suspended magnetic needle, namely, that if placed in a horizontal position, its North-seeking pole dips downward in the Northern hemisphere, and its South-seeking pole in the Southern hemisphere. This fact was first discovered in 1576 by a scientific instrument maker named Norman, and he constructed an *inclination compass* or dip needle, designed to show the angle of dip or inclination which the magnetic needle makes with the horizon. Far more delicate and accurate instruments are now in use at Kew and other great observatories, where daily and minute records are kept of the three magnetic elements, as they are called, namely,

[1] That is to say, it is so called by scientists. Sailors know it as a "variation" map.

[2] Columbus is supposed to have been the first European to discover the declination of the magnetic needle.

the intensity of the earth's magnetism at the particular spot, and the declination and inclination of the needle.

Just as there are places where there is no declination, so there are places where there is no inclination, and these are situated at the farthest possible distance from the magnetic poles. The imaginary line which connects them, therefore, roughly follows the course of the geographical equator, cutting it at two points almost exactly opposite to each other, and situated one in the Atlantic and one in the Pacific Ocean. This line is called the *magnetic equator* or *aclinic line*. *Isoclinic lines* are those which connect places on the earth's surface where the inclination of the needle is the same. At the North magnetic

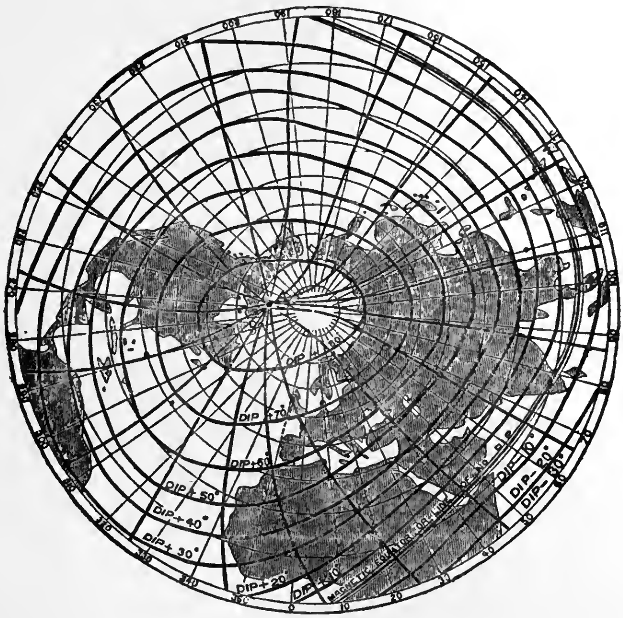

FIG. 14.—Magnetic Map of the Northern Hemisphere. A, North Magnetic Pole.

pole the inclination needle is vertical, and could the South magnetic pole be reached its position would, of course, be the same there. We have therefore very clear evidence that the magnetic force affecting the needle does really reside in the earth itself, and not at any point above its surface, for were this the case there would be no inclination. Fig. 14 is a magnetic map of the world showing both the isogonic and isoclinic lines of the Northern hemisphere. It is not possible, however, to construct such maps accurately once for all like geographical maps. The inclination, like the declination of the needle, undergoes annual and other variations; and in fact the minute and careful observations which have been made of late years show that the magnetism of the earth is in as continual a state of fluctuation as the waters of the ocean.[1] Nevertheless, it is possible to determine what these fluctuations are likely to be for a few years in advance, and to construct maps which will hold good approximately for that length of time. The close study accorded to terrestrial magnetism has brought out many curious facts concerning it, one of which is a certain periodicity in the appearance of magnetic storms which makes their greatest frequency coincide with the maximum period of sun spots, *i. e.*, every ten or eleven years. It would seem, in fact, that there is some remarkable connection between the sun and the earth's magnetism. One specially striking proof of this occurred in 1851, when a luminous mass was seen to cross a sun spot, and at the same time the magnetic needle at Kew underwent great perturbations. Subsequent inquiries brought to light the fact that at the same moment one of the most violent magnetic storms ever known was going on in various parts of the earth.

Before closing this chapter it is necessary to call attention to the fact that the effect of the earth's magnetic force on the magnetic needle is simply directive, causing it always to take up a particular position, but not imparting to it any power of locomotion. This is proved by observing the behavior of a floating magnetic needle. It does not move toward the North, though it sets itself so as to point in that direction. Yet if we were to hold a magnet near the edge of the vessel, the needle would instantly move toward that, which seems to necessitate an explanation of its different behavior with regard to the earth. The fact is that in ordinary cases the needle moves toward the magnet because the nearer pole of the latter acts more strongly on one pole of the floating needle than on the other. In the case of the earth, however, both its poles are so far away from the needle that the one which is nearest exerts equal and opposite forces on the latter, forming what is called the *terrestrial magnetic couple*, tending to turn the needle round, but not to cause any movement of translation.[2]

It has already been stated that the earth is able to induce magnetism in steel or iron bars; but, in fact, any steel or iron objects, or masses of those metals, are affected in the same way. Fire-irons which have been allowed to stand for a considerable time in a vertical or inclined position become magnetized, the lower end being a North-seeking and the upper end a South-seeking pole;[3] and the same

[1] These fluctuations in the magnetism of the earth cause what are known as "earth currents," often very troublesome in telegraphy. They always occur during magnetic storms, and there are also exceedingly weak daily earth currents, flowing from the magnetic poles toward the equator.

[2] Any two equal forces acting in opposite parallel directions to each other, on a rigid body, tend to produce a movement of rotation.

[3] That is, in the Northern hemisphere. In the Southern the reverse would be the case.

remark applies to railings, lightning rods, etc. Objects made of steel or of cast iron retain this state of magnetization, but pure, soft iron cannot do this, as it possesses no *retentivity*, or *coercive force* as it is called. For this reason a bar of soft iron magnetized by the earth has the magnetism of its poles immediately reversed with the reversal of their position if it be tapped, that which was a North-seeking becoming a South-seeking pole if turned upward. This phenomenon is very rarely observed, however, in common objects, as the ordinary iron of commerce is not perfectly pure, and therefore possesses a slight retentivity, even the tools in a smith's shop showing faint signs of magnetization.

The most important effects produced in this way by the earth's magnetism are those on iron ships, which during the process of building become, owing to the hammering they receive while under the influence of the earth's magnetism, permanently magnetized, and consequently able to exert a disturbing influence on the compass needle, which is thus in many positions of the ship unable to lie in the true magnetic meridian. Such a result is of course disastrous to navigation, and various methods of obviating it are resorted to. The use of compensating magnets, *i. e.*, masses of iron placed in such a position with respect to the compass that they neutralize the effect of the ship's magnetism on it, is one; but here a difficulty arises from the fact that after a first voyage the magnetism of the ship generally alters, becoming less strong than it previously was, owing to the buffeting of the waves. In fact, for a considerable period every voyage makes a difference to the ship in this way, and the compensating magnets have to be frequently altered, lest they in their turn should disturb the compass needle by over-compensating the magnetism of the vessel. Fortunately, after a time this does become really fixed, but until then so great are the difficulties attending the use of compensating magnets that they are frequently dispensed with, and a table of errors drawn up by careful observation of the magnetism of the ship and continual comparison with the indications of the compass needle is trusted to instead. In the Royal Navy both methods are employed. The extreme importance of care in this respect is demonstrated by the fact that the loss of ships has been known to occur owing to errors in the compensating magnets which rendered the compass directions untrue. Such a disaster has, however, never occurred in the Royal Navy—a fact on which the authorities justly pride themselves.

Frequently a standard compass is placed in the masts, so that it may be as far removed as possible from the influence of the ship's magnetism.

CURRENT ELECTRICITY

PART III.

CHAPTER I.

THE GALVANIC BATTERY.

Definition of an electric current—Direction of the current—Galvanic battery—Description of simple voltaic or galvanic cell—Effects of the current—Its cause—Poles — Electro-motive force — Resistance—Ohm's law — Difference between electro-motive force of cells in series and in parallel — Weakening of current through polarization—Daniell's cell—Grove's and Bunsen's batteries—Principle common to all batteries—Secondary batteries—Possibility of obtaining them due to polarization—Self-induction—"Extra-current" effects —Space surrounding wire conveys the electric current as well as the wire itself—Nature and effects of an electric current the same from whatever source it is supplied—Thermo-electric currents and the thermopile.

IT can hardly be said that in the section devoted to static electricity no mention was made of currents, for all discharge was shown to be a flow, and flow is but another word for current. That which takes place in discharge, however, is momentary, and by a current of electricity a *continuous* flow is nearly always understood. This continuous flow is caused by a maintained difference of potential between one point and another, and when once set up it does not cease until the potential is equalized, any more than a river would cease flowing unless its whole bed became level or its springs were dried up.

By the direction of an electric current is invariably meant *the flow from positive to negative*, though it must not be forgotten that there is always a negative current as well, whose course is exactly opposite, *i.e.*, from negative to positive. In practice this is usually entirely ignored, a fact which does not render it one whit the less important and interesting to those whose inquiries turn toward the nature of electricity. No satisfactory theory can be propounded which does not take into account the double current.

One of the easiest and most familiar ways of producing an electric current is by means of the *Voltaic* or *Galvanic battery*, discovered toward the close of the last century by the researches of two eminent Italian scientists, Volta and Galvani, working independently of each other and on some theoretical points diametrically opposed.

A battery consists of a larger or smaller number of cells or "elements" exactly like each other, and the following is a description of the earliest form of cell. A strip of copper and a strip of zinc are placed, not touching each other, in a glass or porcelain vessel containing an acid liquid (a very weak solution of sulphuric acid is generally used), and are connected by copper wires, starting one from the zinc and the other from the copper plate (Fig. 15). When these wires are joined a current of electricity is set up which flows from zinc to copper through the liquid, and from copper to zinc through the wires, that is, right round the circuit, and it continues to flow thus till the wires are disconnected. The junction between the wire and the copper plate is called the positive pole or *electrode*, because it is there that the positive current *through the wires* begins, and the junction between the wire and the zinc plate is called the negative pole or electrode. This current produces all the same effects as a discharge. The magnetic needle is deflected by it, chemical decomposition is caused, a thin wire becomes heated, and if the ends of the two wires are placed on the tongue a peculiar taste is noticed. All these effects are greatly enhanced by placing a number of cells in series, connecting the zinc plate of one to the copper of the next, and so on, the wires being fixed to the terminal zinc plate at one end and the terminal copper plate at the other. When the cells are thus connected, the current flows from one to the other, but they may be arranged *in parallel*, *i. e.*, all the zinc plates connected to each other, and all the copper plates to each other. The current then divides itself between the cells.

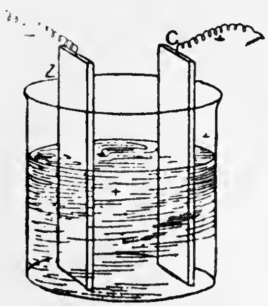

FIG. 15.—Single Galvanic Cell, indicating the direction of the current through the liquid and wires. Z, zinc plate; C, copper plate. The terminal wires join Z to the copper plate of an adjoining cell, and C to the zinc plate of an adjoining cell.

At this point the question naturally arises, What causes the current? A long and fierce war, perhaps hardly yet terminated, was waged by the disciples of Volta and Galvani respecting the right answer to be given. The former maintained that the current was due to contact of dissimilar metals, the latter to chemical action; and since both these causes exist in the battery, and both produce difference of potential, which is as necessary to the existence of a current as difference of level is to a flow of water, it seems very difficult to decide between the two. Probably the right way of addressing the disputants would have been in the words of the traveler called upon to arbitrate in the far-famed quarrel concerning the color of the chameleon,

"You both are right and both are wrong."

It probably is the contact of dissimilar metals which causes the difference of potential in the first instance, and the effort to maintain this potential difference requires chemical action, so that the chemical action, to be presently described, maintains the continuous flow.

The work done in a galvanic battery may be compared to the work done by a pump. The pump raises water from a low to a high level, in opposition to the natural tendency of water to flow from a high to a low level. Work is thus expended *on* the water which is reproduced, minus the amount wasted in friction in the pump, *by* the water as it flows back to its original level. In a galvanic battery electricity is raised from a low to a high potential in opposition to its apparent tendency to flow from a high to a low potential. Work is thus done *on* electricity which is reproduced, minus the amount wasted in overcoming the resistance of the battery cells, *by* electricity as it flows back through the outer circuit to its original potential. What happens *inside* the cells of a battery, then, is that an electric current is driven against a difference of potential (or of electric level), and that a difference of potential is consequently produced and maintained between the terminals or electrodes of the battery. What happens *outside* the battery is that a flow of electricity takes place between the terminal at high potential to that at low potential, so that the direction of the current is with the slope of potential, and work is done by it on its road. Electricity is raised from a low to a high potential inside the battery, and caused to flow from a high to a low potential in the same circuit outside the battery, by what is called *electro-motive force.* No electric current can exist anywhere without an electro-motive force; and since in very many instances it may also be said that no current can exist without a difference of potential, these two terms, electro-motive force and difference of potential, are often regarded as interchangeable. Yet they do not express the same thing. Electro-motive force may cause, or may be the result of, difference of potential, or may exist without it, whereas difference of potential can not exist without electro-motive force. Moreover, it is necessary to remember that though electro-motive *force* is thus named, it is not, accurately speaking, a force at all. It does not act on matter, which is the characteristic of force. It acts on electricity, whatever that may exactly mean. And perhaps the most comprehensive definition which can be given of it is, that it is "the ratio of the rate of doing work in the circuit to the current flowing."

It has already been stated that, however good the conductor through which an electric current is flowing may be, the latter always encounters a certain amount of obstruction or *resistance* on its road, which may be considered analogous to friction in the case of ordinary matter. The power of the current to overcome this resistance depends on the force with which it is being driven along (on the electro-motive force); and the strength of the current, by which is meant the quantity of electricity flowing per second past a cross-section of the conductor conveying the current, increases in direct proportion to the increase of potential difference. It was ascertained first by Ohm, and has since been carefully proved by others, that in a metallic conductor of the same material, dimensions and temperature, the ratio of potential difference to current-strength never changes, and may be called the *resistance* of that particular conductor. This statement is known as *Ohm's law*, and has now been proved true for liquids. Its various applications are of the greatest importance and interest to practical electricians.

When the cells of a battery are connected in series, the sum of their respective electro-motive forces is the electro-motive force of the whole battery. When they are in parallel, the electro-motive force of one cell equals that of the battery. The electro-motive force of any cell is independent of its size, and is affected only by the materials of which it is made.

The current in the earlier batteries could only be maintained a short time, owing to the rapid decrease in its strength caused by the very chemical action which produced and sustained it. This chemical action consists in the dissolving of the zinc in the acid, by which means sulphate of zinc is formed and hydrogen gas set free. The latter forms in bubbles on the copper plate, and there does a two-fold mischief. In the first place, being a bad conductor, it greatly diminishes the effectiveness of the copper; in the second, being itself an electro-positive substance (becoming positively electrified by contact with other substances), it tends to set up an opposing electro-motive force in the battery; in other words, a second positive current flowing in an opposite direction to the first, and consequently much weakening its action. A battery in this condition is said to be polarized, and various cells have been made by different electricians to prevent its occurring, and so render the current *constant*, *i. e.*, enable it to maintain the same strength for a long time together. Daniell's (Fig. 16) was the first, and both it and various modifications of it

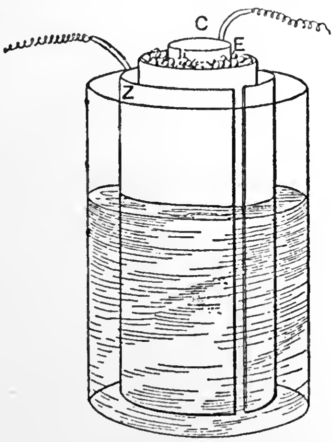

Fig. 16.—Daniell's Cell. Z, zinc plate; C, copper plate; E, porous earthenware partition. The vessel containing the liquid is represented as made of glass, but glazed stoneware is very frequently used, and a zinc rod often takes the place of C in the figure, the copper plate being then situated at Z.

are still much used. Instead of one, two liquids are employed in it, one in contact with the zinc, and one with the copper plate, which are sometimes rolled cylinder fashion, and divided by a porous, unglazed earthenware partition. The liquid, which is in contact with the copper plate, contains sulphate of copper as well as sulphuric acid. The effect of the whole arrangement is to intercept the hydrogen on its road, and instead of it particles of copper drawn from the sulphate of copper contained in the liquid are deposited on the copper plate, which, consequently, cannot lose in efficiency.

Another form of battery much used is Grove's, where platinum is substituted for copper. Though capable of maintaining a current of the same strength for several hours at a stretch, the expense of the platinum constitutes a disadvantage in this battery ; and Bunsen contrived one greatly used in laboratory experiments in which graphite, hard gas carbon obtained from the interior of gas-retorts, is used instead of either platinum or copper.

There are many other batteries unnecessary to describe here, their suitability varying with the purpose for which they are employed. One principle, however, is common to all. No battery can produce a current giving sensible effects unless there is a sensible consumption of its materials by chemical action, any more than a fire will give out sensible heat without a sensible consumption of coal. The material which is "burned" in a battery is generally zinc, which, being almost at the head of the electro-positive series (see p. 24) and very readily oxidisable,[1] has not hitherto been replaced by another less expensive substance. In consequence of this it was found impossible to utilize electric currents on a large scale in any work, such as electric lighting, where powerful currents were required, till some other method than that of galvanic batteries could be employed to generate them, for the consumption of material being proportional to the strength of the current, a large quantity of zinc must be used up in order to produce a powerful current for a considerable time. In telegraphy, where a weak current suffices, this objection does not apply. It should be mentioned that it is necessary to use either perfectly pure or amalgamated zinc, otherwise chemical action goes on, and the zinc dissolves even when the current is not passing, which "local action," as it is called, causes much needless waste.

Before quitting this subject, mention must be made of what are called *secondary batteries*, in which the energy of a current may be stored up as chemical work, and again given out in the form of electric energy. They are also called *storage batteries*, and an opinion is often held by the unscientific that electricity itself is stored. Such is not

[1] It is absolutely necessary that one of the metals employed in a battery should have a great affinity for oxygen, as it is this affinity which first starts the chemical action in the cells.

the case, however; it is the energy of the current which is stored in the form of the products of chemical decomposition, and when this stored-up energy is freed, an electric current is again set up and chemical recombination begins. A secondary battery cannot commence to work of itself. It needs in the first instance to be "charged," *i. e.*, a current must be passed through its cells from an external source, in order to produce the chemical decomposition in which the work of storage consists. When this has been done for a sufficient length of time, the two batteries are separated, and the poles of the secondary being connected, a current is immediately set up, having all the properties of, and being able to perform the same work as that from an ordinary galvanic battery. There is no necessity to use the secondary battery at once; it will remain "charged" for a considerable time, and in this fact consist its importance and convenience. The method of charging by a galvanic battery, however, is very expensive, and in consequence no wide use could be made of the storage principle until other means of charging were available. The dynamo machines, to be described in a future chapter, supplied this want, and secondary batteries have consequently come into great request, being specially useful in electric lighting and locomotion.

The possibility of obtaining secondary batteries is really due to polarization. We have already seen (p. 75) how an opposing electromotive force may be set up in an ordinary battery by the deposit of hydrogen on the negative electrode, causing after a time a second positive current flowing in an exactly opposite direction to the first, and so weakening its action. It is this, the polarization current, which is utilized in secondary batteries, and consequently the current in them flows always in the opposite direction to that of the charging battery. Ritter first discovered the principle of secondary batteries, called also accumulators, in 1803, and many years after the eminent French electrician, Gaston Planté, showed how it could be turned to practical use. Faure's storage battery, an improvement on Planté's, is now most generally used.

It is usual and convenient to speak of the conducting wires as though they alone conveyed the current, but theoretically, and as a true explanation of what happens, this is not the case. We have already seen what an important part is played in the phenomena due to static electricity by the insulating medium, and its function in the case of electric currents is equally necessary, for it will easily be understood that though the wires *appear* to convey the current, the surrounding space must take part in the action also, because within such a space the magnetic needle is affected, and other magnetic and electric phenomena occur. We cannot therefore regard the wire so much as a sort of pipe through which something or other is passing, as the centre of a disturbance in the ethereal medium, which disturbance is propagated along the outside as well as through the wire. It is, in fact, now considered that the energy of an electric current travels entirely through the insulating medium, and not through the wire at all, the function of the latter being to dissipate, not to transmit, the energy it receives. By this dissipation, however, it enables the surrounding medium to continue transmitting more energy, instead of taking up a passive strained condition, such as exists, for instance, in the dielectric layer of a condenser.

This fact, that it is really the space round the wire, and not the wire itself, which conveys the energy of an electric current, explains a phenomenon which was for some time not understood, viz., that an electric current does not instantaneously rise to its full strength when circuit is made, nor instantaneously cease when it is broken. A very slight, but still measurable, delay occurs in both instances, and in the latter the sudden breaking of the circuit will often occasion sparks, showing that the current, unable to stop at once, bursts through the insulating medium interposed with an outbreak of heat and light. Water, which has been several times used as presenting an analogy to electrical phenomena, affords one also here. Water enclosed in a pipe cannot be set in motion suddenly, or if already in motion cannot be suddenly stopped, except by the exertion of a force which is very likely to burst the pipe. With water these two effects are due to inertia, a universal property of matter which can neither start nor stop moving unless force be brought to bear on it. Since an electric current exhibits the same peculiarity, we are naturally led to ask whether that also possesses inertia, and the interest of the question lies in the fact that if it did, electricity would be proved to be a form of matter, however widely different that form might be from those with which we are familiar. But though in the instances cited above (which used formerly to be called " extra-current " effects), electricity appears to possess inertia, in other equally important ways it seems entirely devoid of it. Inertia where it really exists produces well-defined mechanical effects, and examined by any mechanical means an electric current shows no sign of it. The fact is that the effects observed on making and breaking circuit, as well as others of a similar nature, are due not to the inertia of electricity, but to the electro-magnetic inertia of space (or rather of the medium which fills space), and this is quite a different thing. As we have seen, the space surrounding a wire conveying an electric current acquires the property of producing magnetic effects. Such a space must therefore be in a state of magnetization ; but it neither acquires nor loses this condition instantaneously, and in consequence causes those phenomena (known as self-induction phenomena), which appear to be due to the inertia of the current itself.

In whatever way an electric current is given rise to, its nature and effects are essentially the same; and therefore, though one source only, the galvanic battery has yet been described, it will be well to give in the ensuing chapters some more detailed account of the various effects produced. Before doing so, however, a brief mention may be made of what are called *thermo-electric currents.* These arise from setting up a difference of temperature between two junctions formed of two different metals, the effect being more marked when bismuth and antimony are used than with any other metals. Two metals joined for the purpose of giving rise to an electric current through inequality of temperature are called a *pair*, and a number of these pairs may be united so as to form a kind of battery, which is known by the name of a *thermopile*, every alternate junction being either heated or cooled above or below the temperature of the rest of the circuit. When a difference of temperature is set up between two junctions of bismuth and antimony the current flows from bismuth to antimony across the hotter junction, and from antimony to bismuth across the colder, the hotter junction being cooled and the colder warmed during the process, so as to bring them to the same temperature as the rest of the circuit, when the electro-motive force (called *thermo-electro-motive force*) and consequent difference of potential causing the current cease. The currents thus produced are of a low electro-motive force, though some thermopiles have been constructed which generate currents strong enough to depose metals from their solutions, and they have even been made of some practical use in this way. The most usual and important function of the thermopile, however, is to act as an extremely delicate thermometer able to indicate the very smallest changes in temperature, and for this purpose it is invaluable.

CHAPTER II.

CHEMICAL AND PHYSIOLOGICAL EFFECTS OF THE CURRENT.

Difference in the way solid and liquid conductors convey an electric current—Analogy with heat — Electrolytes — Electrolysis — Electrodes — Anions and kathions—Deposition of metals by electrolysis—Electrolysis of water—The voltameter—Free atoms only appear at the electrodes—Gröthuss' hypothesis—Physiological effects of the current—Galvani's experiments—Results of recent experiments—Exciting effect of extraneous currents on living nerves—Difference between the physiological effect of the passage of a galvanic current and a Leyden jar discharge—And of continuous and alternating currents.

Chemical Effects.

AN electric current does not flow in the same way through solid conductors and through liquids. In the former it does not travel *with* the molecules of matter, but in some way *through* them, whether we picture it doing so, as water filters through sand, or as passing from one molecule to another like heat. Heat itself, however, travels in two ways, by what be call conduction in solids, and by convection in liquids and gases. In conduction there is an increased vibration of the molecules communicated from one to the other; in convection there is an actual double journey of molecules, the hot, light ones rising to the top, and the cold, heavy ones sinking to the bottom. Through most liquid chemical compounds electricity also travels by a kind of convection. There is a double procession of charged atoms, the positive all going one way and the negative the other way, and thus the two kinds of electricity travel with the particles of matter, just as heat does when any liquid is rising in temperature.[1]

In order to produce this double procession of atoms, however, chemical decomposition must take place, and all liquids do not undergo this when an electric current is passed through them. It only occurs when the liquid is a conductor, and turpentile as well as most oils are non-conductors. Again, there are liquids which conduct without being decomposed by the process. Mercury and all molten metals belong to this class, but impure water, as well as acid and saline solutions, undergo decomposition whenever a current is passed through them, whether inside or outside the cells of a battery, and they are known in consequence as *electrolytes.* The process of decomposition is called *electrolysis,* a name originally bestowed by Faraday, and abbreviated from electro analysis. The vessel containing a liquid undergoing electrolysis is called an *electrolytic cell,* and the ends of the wires leading from and to the battery, or the strips of metal (usually platinum) to which the wires are connected, and which dip into the liquid, are the *electrodes.* The positive electrode is called the anode, and the negative the kathode.

The atoms set free by decomposition and attracted to the respective electrodes have been already mentioned. Faraday gave them the name of ions, those which appear at the anode being *anions* (the ones which go up), and those which appear at the kathode kathions (the ones which go down). The latter are regarded as being electro-positive because they move with the positive current toward the negative electrode, and the former as electro-negative because they move against the positive current toward the positive electrode. All metallic atoms are kathions — that is, they appear at the negative electrode, and several metals have been discovered through electrolysis by being disengaged from the substance with which they were united and deposited by themselves at the kathode. Potassium is one of these, and was discovered by Sir Humphry Davy.

When very pure water is submitted to electrolysis, there must be

[1] See "Modern Views of Electricity," by Dr. Oliver Lodge, F. R. S., p. 66.

added to ... a few drops of sulphuric acid, perfectly pure water appearing to act as a non-conductor. This being done, however, the process of decomposition commences at once, oxygen being evolved at the anode, thereby proving itself to be electro-negative and hydrogen at the kathode, thus showing that it is electro-positive. Nearly twice as much hydrogen is given off as oxygen in consequence of the chemical composition of water, which consists of two parts of hydrogen to one of oxygen. If it is desired to collect the gases thus set free, an apparatus like that shown in Fig. 17, and known as a *voltameter*, must be used. It consists of a vessel containing slightly acidulated water, in which are immersed two strips of platinum connected by wires with the respective poles of a battery. The strips of platinum are the electrodes of the voltameter, and platinum is used because it resists the action of every acid, and is not easily oxidizable. Consequently it does not tend to set up other chemical actions besides that of the current in the voltameter. The two inverted tubes over the platinum strips serve to collect the gases; bubbles appear at the surface of the water with which they are originally filled, and as this happens the level of the water sinks, the upper part of the tube over the anode becoming filled with oxygen, and that over the kathode with hydrogen.[1] The voltameter affords a very direct way of measuring the strength of an electric current, because the amount of chemical action which takes place in a given time is directly proportional to the strength of the current, and within wide limits no other consideration need be taken into account. Copper voltameters are frequently used for practical purposes. Two plates of copper are immersed in a solution of copper sulphate (blue vitriol), and serve as the electrodes, that which is to be the kathode having been first carefully weighed. When the current is passed through the cell, particles of copper are drawn from the solution and deposited on the kathode, while the anode gradually dissolves in the exact proportion necessary to replace the copper taken from the solution. After a given time, the kathode is removed and again weighed, its increase in weight indicating precisely the amount of current that has passed. Though this method of measurement is exceedingly accurate and direct, it can only be adopted in the case of large

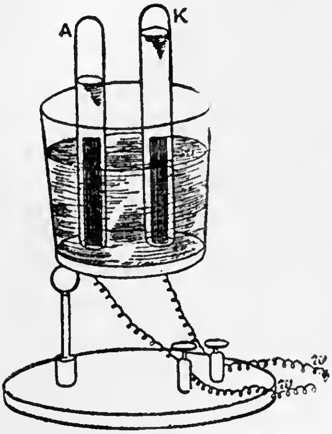

FIG. 17.—Voltameter. A, anode K, kathode.

[1] The form of voltameter above described, though still frequently seen, is becoming very antiquated, and other better forms have been devised.

currents (such as those used in electric lighting); because in the case of small currents, though the amount of chemical action taking place in a given time is always directly proportional to the current strength, it is too minute to be appreciable for many hours, or perhaps days. Weak currents are therefore measured by their magnetic, not their chemical effects, as will be presently described.

There is one very curious fact regarding electrolysis which must not be left unmentioned, viz., that the separated atoms never make their appearance except at the electrodes, and however many cells they may have to pass through before arriving at their respective destinations, nothing whatever is seen of them on the road. The only explanation which seems to account satisfactorily for this remarkable phenomenon is that known as Gröthuss' hypothesis.[1] He supposed that each molecule of the electrolyte underwent a continual decomposition and recomposition. Thus, taking water as an instance, each molecule of which is composed of one atom of oxygen to two of hydrogen, the first molecule decomposed at the positive electrode sets free one atom of oxygen and two of hydrogen. The latter immediately combine with the oxygen of the second molecule, whose hydrogen is in turn set free, and passes on to combine with the oxygen of the third molecule, which is decomposed and recomposed in like manner, and thus the process continues till the negative electrode is reached, where the last two atoms of hydrogen, having no oxygen to combine with, appear free.

Physiological Effects.

Galvani was the first to draw the attention of the scientific world to these, and he, himself, was accidentally attracted to the subject by observing one day that the legs of some newly killed frogs underwent violent contractions at every discharge of an electrical machine with which he was experimenting. This effect was due to the "return shock," viz., to the frogs' legs having become charged by induction owing to the near neighborhood of the electrical machine, and consequently discharging themselves when it did. Not long afterward Galvani discovered that if a living nerve and muscle are touched by two dissimilar metals in contact, an electric current is set up and the muscle contracts. Subsequently he proved that a single metal would have the same effect, and still later that metal could be dispensed with altogether, and the contraction produced by touching the nerve

[1] Gröthuss' hypothesis has been modified in order to meet the further development of chemical science, and it is now more generally supposed that the molecules and atoms of a liquid being always in motion, the passage of an electric current through them controls the direction of that motion by causing the electro-positive atoms to move towards the kathode, and the electro-negative towards the anode, thus causing the decomposition of the liquid and the appearance of the free atoms.

at two different points with a muscle taken from a living frog. Since his time these experiments have been tried on other animals, warm-blooded[1] as well as cold-blooded, and their scope greatly extended. From these researches it has been ascertained, first, that the power of contracting on the passage of an electric current is a distinguishing property of protoplasm, the physical basis of all animal and vegetable life; secondly, that not only do extraneous currents produce certain defined physiological effects, but also that electric currents exist in the living nerves and muscles of all animals, independent of any external stimulus, and that they cease with death, thus establishing an intimate connection between electricity and vital phenomena. What this connection really is, however, remains unknown, and in any case electricity and life are not, as some people seem to suppose, synonymous.

The effect of extraneous currents on living nerves is invariably to excite them to action. Thus, if a feeble current be passed through the eyeball, a brilliant flash of light is seen, owing to the stimulus given to the optic nerve. If the ear be treated in the same way, musical sounds are heard. A current passed through the tongue causes a peculiar taste, and applied to the ordinary nerves of sensation a pricking and stinging are produced. These effects are mostly momentary, occurring only when the circuit is made or broken, but if this be done frequently and rapidly, an equally frequent and rapid succession of the effects may be produced. Where the current is strong enough to cause contraction, tetanus may ensue if the current be interrupted at frequent and rapidly recurring intervals, owing to one contraction not having time to pass off before another commences. The same effect can be produced by alternating currents (*i. e.*, currents flowing alternately in opposite directions).

A galvanic current does not usually give a shock like a Leyden jar, but it will do so, when circuit is made or broken, if the number of cells in the battery is sufficient to give rise to a high electro-motive force, for it is the difference in this respect between a battery and a Leyden jar which causes the difference in their physiological effects. The battery gives out larger quantities of electricity than the Leyden jar, but the difference of potential between its poles is far less than that between the two coatings of the jar, and consequently the electromotive force of the latter is much the greater. The Leyden jar discharge is like a small stream of water falling from a great height; the battery current like a large stream flowing over a very gently inclined bed, and it will be easily understood how much more likely a "shock" is to occur in the former than in the latter case, especially

[1] The experiments are much more difficult to carry out in the case of warm-blooded animals, because their muscles do not retain vitality so long after the general death of the system. Nevertheless, the same results have been obtained.

as the resistance of the human body is very high and requires considerable electro-motive force to overcome it.

The physiological effects produced by continuous and alternating currents are also different, and the latter are both more painful and more dangerous than the former. A person accidentally touching a wire, conveying a continuous current of an electro-motive force not high enough to give a shock causing unconsciousness, could release himself at will. In the case of an alternating current he could not do so, and would suffer painful muscular contractions while remaining fixed. Moreover, the human body can bear without danger continuous currents of a much higher electro-motive force than it car alternating currents.

CHAPTER III.

MAGNETIC EFFECTS OF THE CURRENT.

First discovery of the deflection of the magnetic needle by the electric current—Œrsted's experiments—Ampère's *memoria technica*—Use of galvanoscope—Of galvanometers—Long and short coil instruments—Astatic galvanometer—Disturbing effect of the earth's magnetism—Compensating magnets—Thomson's mirror galvanometer—Relationship between electric currents and magnetism—Wire conveying current acts as a magnet—Possesses a magnetic field—Magnetic behavior of a single wire loop—Equivalent to magnetic shell of the same dimensions—Application of Ampère's rule—Experiment with metallic ring attached to floating battery—Modern theory of magnetism—Amperian currents—Production of rotation characteristic of magnetism—Tendency of a single magnet pole and an electric current to revolve round each other—Rotation of liquid conductors under magnetic influence.

THE magnetic effects of the current are of the greatest importance, and so long ago as 1803 it was known that an electric current deflects the magnetic needle from its true position, tending to place it at right angles with the conducting wire, so as to make it lie, in fact, *across* the current. No use was made of this discovery, however, nor was it even published, and to Œrsted of Copenhagen belongs the honor of having established the fact by careful experiments and brought it to the notice of the scientific world.

Fig. 18 enables Œrsted's experiments to be understood. A magnetic needle is placed between two wires lying in the magnetic meridian. One is above and one below the needle, and both are able to be connected with a battery. If a current is made to pass from North to South through the *upper* wire, *i. e.*, above the needle, the North-seeking pole of the needle is immediately deflected to the

East. If it passes from South to North through the same wire, as in the figure, the deflection of the North-seeking pole is to the West. These deflections are exactly reversed if the current passes through the wire *below* the needle. The North-seeking pole is then deflected to the East when the current flows from South to North, and to the West when it flows from North to South. Ampère has given a very curious *memoria technica* to facilitate the remembrance of the various deflections. Suppose a man swimming in the conducting wire *with* the current and always turning has face toward the needle,[1] all four deflections will then take place toward his left hand, so that keeping this rule in mind the following principle will be understood: "In the directive influence of currents on magnets the North-seeking pole is always deflected to the left of the current."

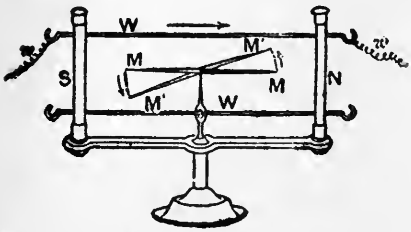

FIG. 18.—W W, wires fixed in the magnetic meridian; M M, magnetic needle lying in its normal position; M' M', the same deflected by a current passing from south to north above it, as indicated by the arrow.

The stronger is the current, the nearer does the deflection of the needle approach to a complete right angle with the conducting wire, but it never entirely reaches this, the directive action of the current being opposed to that of the earth, which tends to keep the needle in the magnetic meridian, so that the position of the needle must always depend on the relative strength of these two forces.

The deflections of the magnetic needle afford a means of indicating the direction and strength of an electric current. An instrument constructed for the former of these two purposes is called a galvanoscope. The simplest of all is made by bending the conducting wire into a rectangular form, so that the current passes in one direction below the needle and in the opposite direction above it, thus acting on it with a double strength, because, as we have already seen, a current from North to South below the needle deflects the North-seeking pole in the same direction as a current from South to North above it.

This apparatus, even when improved by having a great many turns of wire around the needle instead of one, so as to increase the effect of the current,[2] cannot, however, do more than roughly indicate whether it is strong or weak, or which of two currents is stronger. It cannot

[1] To do this when the current passes *below* the needle he would, of course, have to be lying on his back.

[2] Up to a certain limit, the magnetizing effect of the current is increased with every extra turn of the wire, but since resistance is also proportionately increased (owing to the greater length of wire which the current has to traverse), it may at length become so high as completely to counteract the strengthening effect of the coils.

correctly measure the strength of a current relatively to other currents. Yet to know this is of the utmost importance in practical work, and for this purpose, therefore, *galvanometers* are employed. It is unnecessary to enter into any detailed explanation of them. The same instrument will not suit all purposes, but every galvanometer must have a magnetic needle surrounded by a coil of carefully insulated wire. In long coil instruments the wire is turned many, often thousands of times, and is very fine and thin. These instruments are extremely sensitive and are specially suited for very delicate experiments, and to include in circuits where the resistance is already great. In short coil instruments the wire is thicker and has comparatively but few turns, and these should be used in circuits of low resistance. Some definite controlling force is needful in every galvanometer. It may be that of the earth, or of some fixed permanent magnet. In this case the magnet has to be placed at a considerable distance from the needle, so that the latter may be in a field of practically uniform strength. This condition is always perfectly fulfilled where the con-

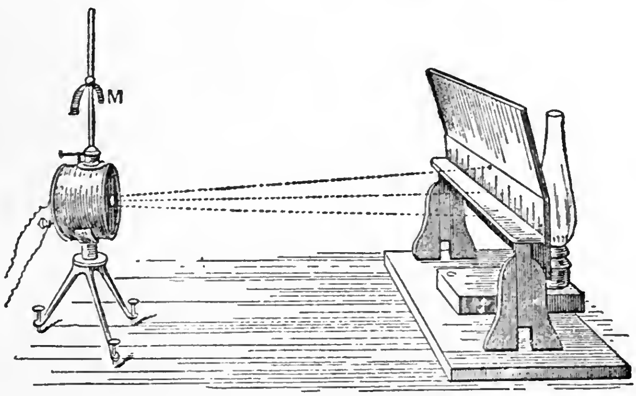

Fig. 19.—Thomson's Mirror Galvanometer.

trolling force is that of the earth's magnetism; but in the case of very sensitive galvanometers, where it is necessary that the controlling force should be very weak, means often have to be employed to obviate the effect of the earth's magnetism. To fulfill this purpose in some galvanometers, use is made of an *astatic pair* of needles, *i. e.*, two needles of equal magnetic strength and size poised carefully one over the other in reversed positions, so that the opposite poles are confronted, each needle being surrounded by a separate coil of wire, the current through one coil being sent in the opposite direction to that through the other. The result of this arrangement is to neutralize the effect of the earth's magnetism on the needles through their mutual reaction, and a very high degree of sensibility can thus be attained. An astatic galvanometer of very great delicacy is Sir

William Thomson's mirror galvanometer, till recently used for signaling through submarine cables. Its general appearance is given in Fig. 19. The readings are made by means of a very small light mirror of silvered glass fastened to the magnetic needle. When the instrument is in use, a beam of light is made to fall on the mirror from a lamp, and is reflected with every movement of the needle to a different point on the scale placed opposite, thus indicating exactly the amount of deflection. The curved metallic piece M is a controlling magnet.

In order that a galvanometer should be able to perform its object, viz., afford a means of accurately measuring the strength of currents, it is necessary in every instrument to ascertain the exact deflections of the needle corresponding to definite currents. When this is known, a basis of comparison is provided, because the same instrument under the same conditions will always show the same deflection for the same current. When the experiments and calculations necessary to determine the deflections of the needle of any particular galvanometer for various currents have been gone through, it is said to be *calibrated.* It is calibrated *absolutely* if the actual currents in ampères producing the different deflections are known; and *relatively* if only the connection between these deflections and the relative current-strengths is determined.

The marked effects produced by electric currents on the magnetic needle, give a very clear indication that there is some close relationship between such currents and magnetism. A yet more striking proof of this is, however, afforded by the fact that an electric current itself possesses magnetic properties. The simplest way of proving this is by passing a battery current through a piece of straight copper wire, and then approaching iron filings to it. The filings at once set themselves at right angles to the wire and cling round it, continuing to do so as long as the current passes; thus showing that the wire has acquired for the time being the power of attracting magnetic substances, if they come within its range of influence. In fact, it produces a magnetic field.

If, instead of a straight wire, a wire curved into a single loop, as in Fig. 20, be used, and the current passed through that, the magnetic field is now enclosed within the loop and coincides with its edges. In fact, such an arrangement as this is exactly like a magnetic shell, which we saw (p. 64) was a magnetized sheet of metal, one surface being entirely North-seeking and the other entirely South-seeking. If the observer be so placed as to look down on the loop, and the current be flowing through it from right to left as shown in the figure, *i. e.*, in the same direction as the hands of a watch move, the upper surface of the

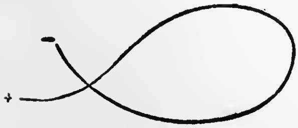

FIG. 20.

loop and the space enclosed will be South-seeking. Referring to Ampère's rule, we should find that a man swimming with the current and facing towards the centre of the loop would be obliged to keep his left side *down*, consequently the North-seeking pole of a magnet would turn itself downward through such a loop. If, however, the current were flowing from left to right, *i. e.*, in the opposite direction to that in which the hands of a watch move, the upper surface of the loop and the enclosed space would be North-seeking. In swimming with the current and facing toward the centre, Ampère's man would have to keep his left side *up*. Transforming him into a magnet, we should find the North-seeking pole urged upward.

A curious and interesting experiment may be made to illustrate these facts by means of De la Rive's floating battery, which consists of a strip of zinc and a strip of copper passed through a large cork and set floating in a vessel containing acidulated water. If the metallic strips be connected by a stout copper ring, and a bar magnet held toward it, the ring will be attracted or repelled according to the pole presented. If the North-seeking pole of the magnet be held toward the South-seeking face of the ring, the latter will be attracted, and will thread itself on to the magnet quite up to the centre. If the South-seeking pole be presented to the South-seeking face of the ring, the latter will be repelled, and if nevertheless forced to pass on to the magnet, will, as soon as let go, rapidly unthread itself, turn round so as to present its North-seeking face, and then re-thread itself up to the centre of the magnet as before. This is exactly how a magnetic shell would behave under similar circumstances, supposing that a hole were pierced through its centre to allow of its passing on to the magnet; and in fact every closed voltaic circuit (of which the loop or ring we have been considering is an instance) is in all respects equivalent to a magnetic shell of the same dimensions. It attracts and repels according to the same laws, and moreover, if placed itself in a magnetic field, it experiences just the same influence as the shell would do. We have therefore here a most striking illustration of the close relationship between magnetism and current electricity, and it will hardly surprise the reader to hear that according to the most modern theory they are in fact identical, only in the latter the flow takes place from one point to another, and may be compared to that of a river, whereas in magnetism the movement is one of rotation, like the motion of water in a whirlpool. According to this theory, a magnet (which consists of a number of infinitesimal magnets) has a separate current of electricity circulating round each one of its molecules, and these currents when a perfect state of magnetization is reached, and all the molecules are set end to end, are parallel to each other. Without entering into details, which might be found tedious and complicated, it is sufficient to state that their effect on external space and objects is exactly the same as though a current were circulating round the outside of the magnet. This is because only the currents belonging to the surface molecules are free to act externally at all, those in the interior being neutralized by their action on each other. The theory of these molecular currents is due to Ampère, and they are called by his name, amperian currents. It is the case that they do satisfactorily explain magnetic phenomena, but it is not probable that they are called into existence by the act of magnetization. They are most likely already present in magnetic, and in fact in all substances. Magnetization merely renders their presence sensible externally, by setting them in a parallel direction through altering the position of the molecules. Those substances, therefore, whose internal structure does not lend itself to such a change, or only with great difficulty, are not capable of magnetization in the ordinary sense of the term. It must be remembered, however, that when a sufficiently powerful external force is exerted, all substances do feebly show signs either of magnetic or dia-magnetic phenomena, and the latter also are explicable by means of Ampère's theory.

That the production of rotation is a characteristic of magnetism can be very easily proved. One simple and striking experiment is described by Dr. Oliver Lodge in his "Modern Views of Electricity."[1] A long piece of gold thread is suspended in close proximity to an upright bar magnet, and a current passed through the thread. The latter immediately begins to coil itself round the magnet, half of it round the North-seeking pole, and the other half round the South-seeking pole, in such a manner that the two halves form a common spiral. If the gold thread were exchanged for a stiff wire, and a flexible magnet used, the magnet would then coil itself round the wire. In fact, it is proved that a single magnet pole would, if free to move, continually revolve round an electric current, and that an electric current would in the same way revolve round a magnet pole. As we know, however, it is impossible to obtain a magnet with one pole, it must always have two, and therefore a rigid magnet and a rigid conductor cannot possibly show this movement of rotation. All they can accomplish is to place themselves at right angles to each other, as we have seen the magnetic needle invariably tends to do when placed over, under, or near a wire through which an electric current is passing.

Liquid as well as solid conductors can be made to rotate under the influence of magnetism. If a vessel containing acidulated water be placed over a powerful bar magnet and electrodes immersed in it, one at the centre of the vessel and one at the edge, the liquid will begin to rotate, and that so forcibly as very likely to cause it to splash over the sides of the vessel when a current is sent through the liquid.

[1] P. 135.

CHAPTER IV.

ELECTRO-MAGNETS.

Definition of the term—Discovery of the way of making electro-magnets—Solenoids—Manner of insulating the coils of an electro-magnet—Shapes of electro-magnets—Way of widening the coils of a horse-shoe electro-magnet—Position of North-seeking and South-seeking poles—Formation of consequent poles—Core of an electro-magnet takes time to become magnetized—Magnetic strength of electro-magnets—Coils with a number of turns only appropriate in a circuit of high resistance — Kind of metal used for the coils a matter of indifference — Reason of the importance of the iron core.

FROM the observations made at the close of the preceding chapter it will be seen that all magnets may perhaps be *electro-magnets*, because without electricity it is probable that neither magnets nor magnetism would exist. The term is not used, however, in this general sense, but refers exclusively to bars of iron or steel made into magnets by being enclosed in a spiral coil of wire through which an electric current is caused to pass. Steel treated in this way becomes permanently magnetized, but a bar of soft iron only retains the whole of its magnetism while the current lasts. Consequently, this being a great practical convenience, it is soft iron which is almost invariably used for the "core," as it is called, of electro-magnets. The amount of magnetism which the core retains when the current ceases is so faint that it seems hardly worth noticing. Nevertheless, as we shall hereafter find, this feeble "residual magnetism" has been made to yield the most important practical results, and it must not therefore go unnoticed.

The principle of electro-magnets was known as far back as 1820, when Arago and Sir Humphry Davy independently discovered that a

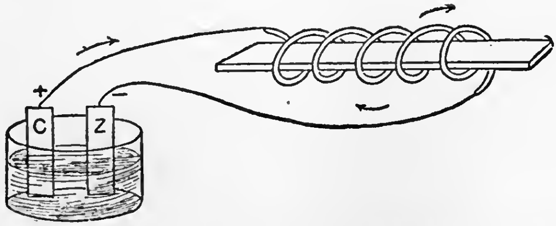

FIG. 21.—Soft iron bar, magnetized by being placed within a wire spiral conveying the current from a single cell.

bar of iron or steel could be magnetized, as shown in Fig. 21, by being enclosed in a wire spiral through which an electric current was caused to circulate. The first practical electro-magnet was, however, made and exhibited by William Sturgeon in 1825, and he is therefore justly regarded as the inventor of this most useful and important appliance of electro-magnetism. Though a soft iron bar is always used in electro-magnets, it is not indispensable. A wire spiral without a core will also acquire magnetic properties, though never to such an intense degree. It is then called a solenoid, and behaves like a bar magnet, setting itself in the magnetic meridian if freely suspended, and having, of course, a North-seeking and South-seeking pole, which have the power of attracting and repelling other magnetic poles, and of attracting and being attracted by magnetic substances. Fig. 22 represents a solenoid arranged for suspension.

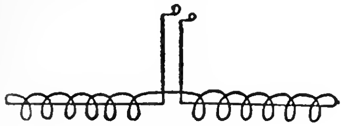

FIG. 22.

In electro-magnets care must be taken that each coil of the wire is separated from the next and from the iron core, for if contact takes place at any point, the current passes from one coil to another instead of round each coil, and its effect is thus weakened; for as has been already stated in a previous chapter, the magnetizing effect of the current is increased by increasing the number of coils in the wire, at least up to a certain point.[1] The insulation of the coils from each other and from the core is effected by covering them with silk or cotton thread, the latter dipped in melted paraffin wax, or with a thin coating of gutta-percha, and they are wrapped as closely round the core as can be managed without weakening the insulation. This is done to avoid the increase in resistance, which the greater length of wire required for wide coils would give rise to. The ends of the core always protrude beyond the coils.

Electro-magnets, like permanent magnets, may be of any shape, but the most usual are the bar and the horse-shoe. Fig. 23 represents the latter in which two coils of wire are used, leaving the central part of the magnet bare. In order that with this arrangement one pole may be North-seeking and one South-seeking, the wire must be wound so that if the magnet were straightened out the coils would all follow the same direction. At whichever end the current enters the coils, the North-seeking pole is always that where it flows round them in the opposite direction to the way in which the hands of a watch move, and the South-seeking pole that at which it flows in the same direction.

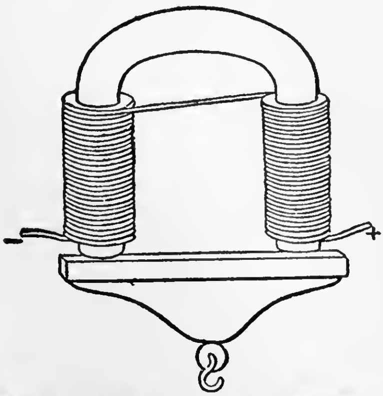

FIG. 23.—Horse-shoe Electro-magnet with keeper and hook for suspending weights.

[1] See p. 85, note.

If the wire is coiled irregularly, at every change of direction a consequent pole is formed, just as happens in the case of an irregularly magnetized ordinary magnet.

The core of an electro-magnet takes time to become magnetized, partly because an electric current does not (as has already been stated, p. 78) attain to its full strength at once, and partly because of the transient inverse induction currents started in the core itself, when the magnetizing current commences to flow through the coils (see p. 98).

Augmenting the strength of the magnetizing current, and augmenting the number of convolutions in the coil of an electro-magnet, alike increase the magnetizing power of the latter. In fact, for low intensities of magnetization the amount of magnetism is approximately proportional to the product of the current into the number of convolutions of wire, but after a certain point is reached this ceases to be true, because as the magnetism becomes stronger and stronger it increases less and less slowly with the product, so that beyond a certain point a very large increase in the product is necessary in order to give rise to a small increase in the magnetism. Nevertheless, as this small increase does take place, it cannot, strictly speaking, be said that such a thing as saturation exists in the case of an electro-magnet. Other considerations beside the intensity of the magnetizing force to which it is subjected, affect the amount of magnetism which the core of an electro-magnet can acquire. The quality of iron of which the core is made, its shape, length and thickness, are all of importance. It must be remembered also, that since the resistance encountered by the magnetizing current increases with the number of coils, it would be a mistake to include an electro-magnet with a great many coils in a circuit of otherwise low resistance, because the total resistance would be thereby so much increased as to weaken the current. A few turns of stout wire would in this instance answer the purpose better, whereas in a circuit which already has a high resistance an electro-magnet with many coils of fine wire is preferable.

The wire used in the coils need not be of any particular metal. Copper is very often chosen, but for this purpose it has no special merit except its small specific resistance, as neither the material nor the thickness of the wire produces any effect on the strength of the electro-magnet. The important thing is that a sufficient quantity of electricity per second should be carried sufficiently often round the iron core to produce a magnetic field of the required intensity between it and them. For this purpose, when stout wire is used, a few turns will suffice, because in this case a considerable quantity of electricity will be carried round the core of the electro-magnet in one convolution, whereas in the case of fine wire a great many turns are necessary, since one convolution only suffices to carry a small quantity of electricity round the core.

It is of interest to know why the introduction of a soft iron core into a wire spiral should so greatly increase its magnetic strength. The explanation is to be found in the fact of the alteration that takes place in the direction of the lines of force. These in an ordinary steel bar magnet run from end to end, and round outside from one pole to another (see Fig. 11, p. 65). In a solenoid (without a core) very few of them do this; they nearly all remain as closed curves round the wire, each separate coil of which acts like a magnetic shell. When the core is introduced, on account of the high inductive power of iron, most of the lines of force in the solenoid are compelled to alter their direction and follow that of those existing in the iron itself, which run through the length of the iron and back from pole to pole, as in the case of the steel magnet already described. Consequently the strength of the poles, being thus reinforced, is very greatly increased.

CHAPTER V.

ACTIONS OF CURRENTS UPON CURRENTS—INDUCTION CURRENTS.

Mechanical reaction of conductors which are conveying electric currents—Due to attraction and repulsion between the currents—Ampère's laws—Ampère's table—Further laws—Induction of one current by another—Primary and secondary coils—Direct and inverse currents—Induction of currents by magnets—Self-induction—Its effect on the primary current—Contact-breakers—High electro-motive force of induction coils—Ruhmkorff's coil—Sparks from induction coils—The aureole—Effects obtained by means of Geissler's tubes—Effect of a magnet on luminous discharge through rarefied air—Induction currents in solid masses of metal—Lenz's law—Experiment with metal disc suspended between the poles of two electro-magnets—Currents of the higher order.

HITHERTO our observations have been confined to the magnetizing effects of an electric current, but another equally important fact demands attention. It is that electric currents act and re-act on each other, causing movements in the conductors conveying them. These movements are due to the mutual attractions and repulsions between the currents, for flowing electricity, like electricity at rest, exhibits these phenomena, though they are governed by entirely different laws, first discovered and studied by Ampère.

He found—

I. That currents conveyed by parallel wires attract each other if following the same, and repel each othe if following different directions.

II. That currents conveyed by wires which are inclined to each other at any angle, are mutually attracted if both flow toward or both flow from the apex of the angle, and mutually repelled if one flows toward and one from it.

Ampère devised an apparatus known as Ampère's table for observing the actions of currents on each other. It consists of a stand with double supports, upon which wire conductors of different shapes may be suspended in such a way as to allow them to rotate, and at the same time connected to a battery, so that a current may be passed through them and the behavior of the various portions of wire with regard to each other be observed. By the help of this apparatus Ampère showed that two parts of a circuit in whatever relative position they may be, experience a force tending to set them in such a direction as to enable the currents they convey to flow in the same path; also that a wire doubled back on itself, so that the current takes a return path close to the one it was following before, does not exert any external force; and further, that a zigzag wire exhibits the same magnetic influence over a not very near portion of the circuit as a straight one. Ampère also demonstrated that a conductor never experiences a force tending to move it in the direction of its own length, because the attractions and repulsions between currents always act at right angles to the currents themselves, tending therefore to make them revolve round each other.

Since a mutual action exists between currents and currents and between currents and magnets, it is not surprising that under certain circumstances one current should be able to induce, *i. e.*, bring into existence, another, and that magnets should also possess the same power. In their case it is exerted whenever a magnet is moved about in the neighborhood of a closed circuit, or when the circuit itself is moved in or across a magnetic field. In the case of currents, a current *whose strength is changing* induces a secondary current in any conductor near it; and currents produced in either of these ways are said to be caused by electro-magnetic induction, and are called *induction currents*. Their discovery is due to Faraday.

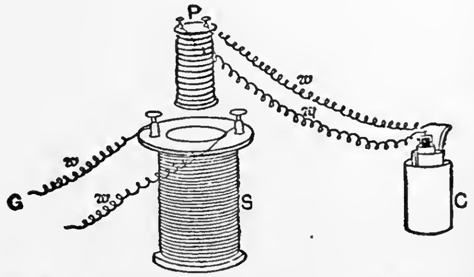

FIG. 24.—P, primary coil; S, secondary coil; C, battery cell; G, position of galvanometer.

In order to show the induction of currents by currents, two coils of wire are necessary, of which one is usually large enough to allow of the other being inserted into its hollow. This is merely for convenience' sake, however, as the relative size of the two coils is quite immaterial so far as the generation of induction currents is concerned. The small coil, which is called the *primary*, and is made of stoutish wire with few turns, is connected to a battery; and the large coil, in which the wire is fine and often coiled many thousand times, is called the *secondary*,[1] and connected to a long coil galvanometer, as shown in Fig. 24.

When the battery current is passed through the primary coil and the latter inserted into the hollow of the secondary, the galvanometer needle indicates a momentary current in the *opposite* direction to that in the primary coil, and the same effect is produced if the current starts in the primary while it is lying in the hollow of the secondary. When the former is withdrawn, or when circuit is broken while it is lying in the hollow of the secondary, another current is indicated in the latter in the *same* direction as that in the primary. This is called a *direct current*, and the former an *inverse current*. Inverse currents are produced in the secondary coil whenever a current in the primary coil begins, increases in strength, or approaches nearer; direct currents in the secondary coil occur whenever that in the primary ends, decreases in strength, or recedes. Neither inverse nor direct currents ever occur except when a current in the primary starts or stops, or when one of the coils is moved (for moving the secondary nearer to or farther from the primary produces the same effect as moving the primary itself), and their duration is only momentary.

To show the induction of currents by magnets, it is merely necessary to replace the primary coil of Fig. 24 by a bar magnet. It will be found that whenever the magnet is inserted in, or approached to the hollow of the remaining coil, a current is produced in one direction, and a current in the opposite direction whenever the magnet is taken out or withdrawn to a greater distance.

Beside the induction of one current by another, there is also the induction of a current on itself, called more shortly *self-induction*, to which brief reference was made in a former chapter. By it is really meant, that if two portions of the same circuit are placed side by side, the sudden commencement or cessation of a current in one portion tends to induce a momentary current in the other, just as if the two portions belonged to separate circuits. Thus, suppose we have a wire doubled back on itself, as in Fig. 25, and the primary current flowing in the direction indicated by the single barbed arrows, at the commencement of such a current there would be a tendency to induce a momentary inverse current flowing in the direction of the double

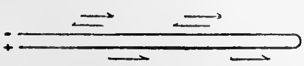

FIG. 25.—Diagram to illustrate Self-induction.

[1] The result of having stout wire with few turns in the primary, and fine wire with many turns in the secondary coil, is that a large current of low electro-motive force induces a comparatively small current of very high electro-motive force.

barbed arrows; and at the cessation of the primary current a tendency to induce a momentary direct current, flowing, of course, with the single barbed arrows.[1] This induction has the effect of weakening a current at its start (thus delaying its growing to its full value), and strengthening it at its cessation, which is thus retarded. In fact, since the induction of the current in one part of a circuit takes place on another part of the same circuit across the intervening medium, energy is transferred to the latter while the circuit is closed, and the current remains constant in strength, but is given back to the circuit again to produce the "extra current" on the stoppage of the main current. This is the reason why sparks are obtained on breaking circuit. They are much more brilliant if a coil of many turns be included in the circuit; and if the coil contains a soft iron core, this again increases the sparking power. There are various automatic contrivances called contact-breakers, or interrupters, used for making and breaking circuit with regularity and rapidity, but a detailed description of them is unnecessary for the present purpose.

Induction currents have an enormously high electro-motive force, and very striking effects can consequently be produced by them. These are shown in a marked and powerful way by the induction coil or inductorium, often known under the name of *Ruhmkorff's coil*, as that inventor did much to perfect it. Its most important parts are, of course, a primary and secondary coil, placed one within the other, and the former connected with a battery, and containing a core of straight soft iron wires. Under the coils there is a condenser, which is placed within a flat wooden box and consists of sheets of tinfoil, separated by sheets of paraffined paper, each alternate piece of tinfoil being electrically connected, so that the whole set forms two series corresponding to the inner and outer coatings of a Leyden jar. A contact-breaker and a commutator or key, whose use is to reverse the direction of the battery current whenever the operator chooses, complete the apparatus. The wires from the primary coil are, as has already been said, connected with the terminals of a battery, and those from the secondary with the condenser, the use of this latter arrangement being that the spark on breaking circuit may be mitigated by lessening the amount of extra current in the primary coil, some of the electricity flowing into the condenser, instead of to the point where the break is made.

The sparks from an induction coil are extremely powerful, and often attain a great length. From eighteen to twenty inches is not at all unusual with a large instrument, and sparks a metre long have been obtained from some of its most modern forms. These sparks

[1] In a simple circuit, such as that represented in the figure, there would be very little self-induction, however, whereas in a circuit coiled many times on itself, there would be a great deal.

are not exactly the same as those obtained from an electrical machine or a Leyden jar; for beside the spark proper, there is an aureole or glow which surrounds it, and which by the help of a suitable apparatus can be detached from it, thus showing that the two appearances are caused by different discharges. Experiments of various kinds seem to prove that the sharply-defined spark is analogous to that given by a battery on breaking circuit, and that the aureole is caused by the quiet combination of the opposite kinds of electricity in the same manner as in a galvanic current.[1] The sparks from induction coils are specially suitable for passing through Geissler's tubes, and are very often used for this purpose in preference to those from an electrical machine. Very beautiful luminous effects are then obtained, especially if the tubes are made of uranium glass, or contain a solution of quinine or other "fluorescent" liquid. By fluorescence is meant the property possessed by some substances of changing the color of rays of light through altering their arrangibility; phosphorescence is the power of becoming self-luminous, a property which can be conferred by the passage of an electric discharge on that part of a very highly rarefied gaseous medium near the negative pole. The phenomena of fluoresence and phosphorescence, though somewhat complicated, present points of the highest interest and importance, and a hope seems even to be entertained by some of our leading scientists, that in the course of time discoveries will be made enabling us to produce for ordinary purposes artificial light of this description, which is unaccompanied by heat. In fact, experiments in this direction were made by Professors Ayrton and Perry so far back as 1879.

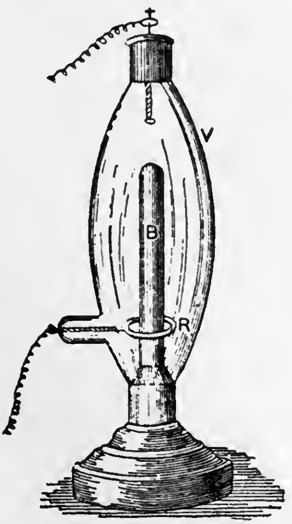

FIG. 26.

An exceedingly interesting and instructive experiment can be made with a magnet on the luminous discharge in a Geissler's tube, such a discharge possessing the properties of an electric current so that it deflects the magnetic needle, and is itself capable of being acted on by a magnet. Fig. 26. will enable this experiment to be understood. A soft iron bar (B) is enclosed in an exhausted glass vessel (V), and is surrounded at the lower end by a metallic ring (R), and carefully insulated. The terminals of a battery are then connected, one with the upper end of the apparatus and the other with the metal ring, and immediately a sheaf of luminous rays descends

[1] "Electricity in the Service of Man," p. 199.

toward the ring, surrounding the soft iron bar. If while the luminous discharge is thus passing, one pole of a magnet be held under the vessel, the iron bar becomes magnetized, and the rays of light begin to revolve round it, thus giving a striking proof both of the rotary tendency of the magnetic forces and of their effect on an electric discharge.

It must not be supposed that induction currents show themselves only in wires. Solid bars or masses of metal of any shape are susceptible of them, and a magnet moved in the neighborhood of a lump or plate of metal, or the starting or stopping of an electric current near it, induces in it currents which, owing to the resistance they encounter, very rapidly transform their energy into that of heat, and while they last tend to stop the motion of the magnet which gave rise to them. This they do in accordance with a law, known as *Lenz's law*, from the name of its formulator, by which all induced currents flow in such a direction that their reaction tends to stop the motion producing them. They thus, in fact, offer a mechanical resistance, which is experienced by any conductor constrained to move across the lines of force in a magnetic field. A curious and striking instance can be given of this by suspending a metal disc by a twisted thread, between the poles of two powerful electro-magnets. While the magnets are inactive the disc revolves rapidly through the untwisting of the thread, but directly the current passes through the coils the disc stops dead, and if forcibly compelled to rotate, grows rapidly hot, showing how powerful is the resistance encountered.

It has been discovered not only that primary currents give rise to secondary currents, but also that the latter are themselves able to induce currents in closed circuits near them, and not in any way connected with the primary. Thus, suppose that near the secondary coil a third coil is placed, and near this a fourth. When a current commences in the secondary coil an inverse current is induced in the third coil, and a direct current on its cessation. These currents in the third coil give rise in like manner to momentary currents in the fourth coil, and the process may be almost indefinitely repeated. Currents thus induced by the action of that in the secondary coil, are called *currents of the higher order*, and are said to belong to the third, fourth, or fifth order, etc., according to the remoteness of their generation from the secondary.

CHAPTER VI.

PRACTICAL UNITS OF MEASUREMENT FOR ELECTRIC CURRENTS.

Ways of measuring electric currents—Need of units of measurement—C. G. S. units those on which "absolute" electro-magnetic units are founded—"Practical units" those in common use—Recapitulation of what there is to measure in electric currents—Electro-motive force—Resistance—Strength—Quantity—Names and definitions of practical electro-magnetic units—Other units derived from these to express larger and smaller quantities—Necessity for a unit of capacity—The Farad and Microfarad.

ELECTRIC currents can be measured in various ways—by their influence on the magnetic needle,[1] by the amount of chemical action they give rise to,[2] and by their heating effects. In order to measure them, however, we must have some scale of measurement to go by. We need, for instance, a definite unit in order to calculate the strength of any given electric current, just as we need a definite unit of time so as to calculate the number of hours in a day or of days in a year.

All physical quantities, such as force, volume, velocity, etc., can be expressed in terms of length, mass, and time, and each of these requires a unit of its own on which to base its measurement. In science the almost universally adopted units are—for length the centimetre, for mass the gramme, and for time the second. The centimetre is 0.3937 (considerably less than two-thirds) of an inch, the gramme equals rather more than fifteen grains troy, and the value of the second is practically known to every one. The system of units derived from these as fundamentals is called, after their initials, the C. G. S. system, and the "absolute" electro-magnetic units, like all absolute derived units (such as those of area, volume, velocity, etc.) belong to it. With the absolute electro-magnetic units such a work as the present need not concern itself. It will suffice to obtain a tolerably clear idea of what are called the *practical units*, which are founded on the absolute units and are those in general use, some of the absolute units being too large and some too small for ordinary purposes.

Before giving a list of these practical units, which are named after various eminent men whose discoveries in electrical science have been specially notable, it will be well to recapitulate exactly what there is to measure in an electric current.

In the first place, there is the *electro-motive force* (nearly always indicated by the letters E. M. F.), without which, as has already been

[1] See chap. iii. [2] See chap. ii.

stated in Chapter I., p. 74, no current can exist, and on which the power of the current to overcome resistance depends.

Next in order to electro-motive force comes *resistance*, defined in a former chapter as the opposition offered to the passage of electricity through any material substance, and also as the ratio of potential difference to current strength, which in a homogeneous conductor at a given temperature is constant. Resistance, of course, varies inversely as conductivity. The better the conductor the less the resistance, the worse the conductor the greater the resistance. Every substance has its own specific resistance, just as every substance has its own specific heat.[1] In the case of metals, the order of least resistance for electricity is very nearly the same as that for heat; so that silver, which is the best heat conductor, is one of the best electrical conductors also, and mercury one of the worst. In the same substance the resistance varies with difference of temperature, in metals increasing with increase of temperature, in insulators decreasing. Other causes also affect resistance; it increases with the length of wires, and decreases with their thickness. The resistance of a stout metal rod would be nothing in comparison with that of a piece of telegraph wire of the same length, and that of the latter, if only 100 yards long, would be a negligible quantity compared to what it would attain if the wire were 100 miles long.

Resistance is usually measured by comparison with that offered by standard coils of wire whose resistance at a given temperature is known. They are called *resistance coils*, and are wound double, so that their interaction may preserve them from all external electric and magnetic influence, and are usually made of German silver, whose resistance changes little with change of temperature, or of an alloy of silver and platinum, which possesses the same property, or of platinoid. Alloys of metals, of course, have different resistances from the metals themselves, and even the slightest impurity affects them in this respect.

By the *total resistance* of a circuit is meant that offered by the whole circuit, and by the *internal resistance* that which is encountered in the generating source of the current—as, for instance, in the battery cells of a galvanic circuit.

Besides electro-motive force and resistance, there is the *strength of current* to be measured, which is evidently dependent on them both. Given a high electro-motive force and a low resistance, we shall get a strong current, just as given water running through a pipe at high pressure and with no impediment, we shall get a powerful outflow at the tap. But given the same electro-motive force and a high resistance,

[1] The specific heat of any substance is the amount of heat required to raise it 1° C. in temperature. The specific resistance is the "resistance in 'absolute' C.G.S. units (*i. e.*, in thousands millionths of an ohm) of a centimetre cube of the substance."

we shall get a weak current, just as we should get a feeble outflow of water at the tap in spite of the former being at high pressure, if it had to flow through a partially choked pipe. In fact, strength of current means the quantity of electricity flowing past a given point in a given time, and therefore it is necessary to be able to measure, and to have a unit of measurement for

Quantity of electricity. Electro-motive force is indeed independent of it, but since strength of current is actually the quantity of electricity flowing per second past a given point in a conductor, this strength can be augmented in two ways, either by increasing the electro-motive, *i. e.*, the driving, force, or by making the current larger. The pressure of falling water in a pipe is not increased by increasing the size of the pipe, but by increasing the difference of level ; yet, other things being equal, the strongest stream of water will issue from the largest pipe simply because it is the largest and holds the most water. In the same way electro-motive force is not increased by doubling or trebling the quantity of electricity conveyed by a given conductor, but by doubling or trebling the difference of potential between the two ends of that conductor ; yet the electro-motive force being the same, a stronger current will flow through a thick than through a thin wire, merely because its thickness allows of the passage of a greater quantity of electricity through the same distance in the same time.

Having thus described what there is to measure in an electric current, the list of units can now be given.

The volt (derived from Volta) is the unit of electro-motive force.[1] It is defined as the difference of potential that must be maintained at the ends of a wire of one ohm resistance, so that a current of one ampère may pass through it.

The ohm is the unit of resistance, and is equivalent to the resistance of a column of mercury one millimetre square and 106 centimetres in length, at a temperature of 0° Centigrade. One mile of ordinary iron telegraph wire has a resistance of from 10 to 20 ohms.

The ampère is the unit of strength of current, and may be defined as a current strong enough to deposit 0.000329 (329 millionths) of a gramme of copper per second on one of the plates of a copper voltameter.

The coulomb is the unit of quantity, and means that quantity flowing in one second past the cross-section of a conductor conveying an ampère.

[1] For practical purposes some particular cell (a standard Daniell's, for example), whose electro-motive force is as nearly as possible one volt, and whose constancy can be depended on, is often used as a standard of electro-motive force ; but this does not form the scientific standard of the volt, which is not dependent on the electro-motive force of any cell or chemical combination.

Since quantities almost indefinitely greater and smaller than those signified by the above units have to be measured by electricians, prefixes are often used expressing one thousand or one million times more, or one-thousandth or one-millionth part, so as to avoid the inconvenience of writing and reading such enormous numbers as would otherwise be necessary. For instance, the currents in ordinary telegraphy are not measured by ampères, but by milli-ampères (or thousandths of an ampère), and the resistance in a good telegraph insulator not by ohms, but by megohms (millions of ohms). The electro-motive force of a lightning flash would be measured, if it could be measured, by mega-volts (millions of volts), and the strength of telephone currents by micro- (millionth) ampères.

It will be understood that though these practical units have been mentioned only with reference to current measurement, they can also be used for electro-static purposes. The electro-motive force of a Leyden jar (*i. e.*, of the difference of potential between its two coatings), or of any condenser, would be measured in volts, just as would be the electro-motive force of a galvanic battery ; and the resistance of any conductor would be expressed in ohms.

It is clear that the electro-static capacity of a conductor, *i. e.*, the amount of electricity which, owing to its size, shape, and position, with reference to other conductors, it is capable of accumulating, must be of great importance in much practical work, and therefore a unit of capacity needs to be added to those already named. It is called a *farad* (from Faraday); and a condenser, which must naturally be the standard of capacity, has a capacity of one farad, when a potential difference of one volt between its two sets of plates charges each of them with one coulomb. A condenser constructed of tinfoil and paraffined paper, like that described in connection with induction coils, is most frequently used in practical work, but if made on the scale of one farad as a unit, it would be so enormous as to be almost impossible of construction, and quite unmanageable for all ordinary purposes if it were constructed. The practical unit of capacity is therefore in reality the microfarad (one-millionth of a farad), and condensers are made graduated in microfarads. Even then, for some purposes (such as "duplexing" submarine cables), condensers containing many thousand square feet of tinfoil are necessary.

PRACTICAL APPLIANCES OF ELECTRICITY

PART IV.

CHAPTER I.

MAGNETO-ELECTRIC AND DYNAMO-ELECTRIC MACHINES AND ELECTRO-MOTORS.

Number of practical electrical appliances in modern days—Magneto-electric machines—Pixii's machine—Clarke's machine—Wilde's machine—Siemens' cylindrical armature—Dynamo machines—Their principle—Origin of their name—Now includes magneto-electric machines—Siemens' first self-exciting dynamo—Gramme machine—Principle of Gramme ring—Continuous current machines—Alternate current machines—Various kinds of dynamos—Requisites for a good dynamo—Electro-motors—Their work the converse of that of dynamos—Powerful currents generated by dynamos—Currents of high E. M. F. used for electric lighting—Transformers.

THE practical appliances of electricity in our day are so numerous and so important that it is difficult to know with which to begin. The electric telegraph is the oldest, and has already attained a familiarity which, in this instance, however, certainly does not breed contempt, for no later invention can surpass or perhaps even equal it in the magnitude of its effects on the whole human race. Nevertheless, the more recent adoption of electric lighting and electric transmission of power gives them for the moment a greater prominence in the eyes of the world; and since it is impossible to gain any notion of their working principles without some knowledge of what is meant by the three classes of machines whose names head this chapter, it will perhaps be as well to commence with them.

Priority of date belongs to the magneto-electric machines, the first of which was constructed in 1833 by Pixii, a scientific instrument maker in Paris. His apparatus consisted of a steel horse-shoe magnet, which was made to revolve rapidly before two wire bobbins, so that its North-seeking and South-seeking poles passed alternately in front of them. Currents were thus induced in the bobbins which changed direction at every half revolution of the magnet, but which, owing to the way in which the bobbins were wound,[1] would, if the coils were laid end to end, flow through both in the same direction at the same time.

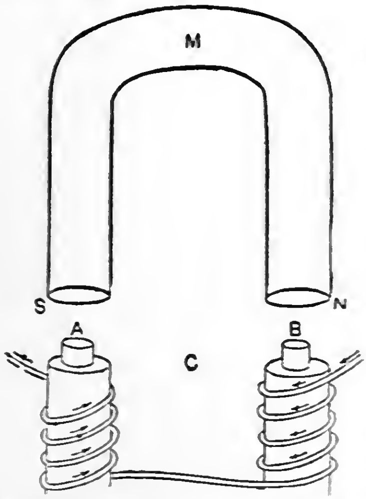

FIG. 27.—To illustrate the principle of Pixii's Machine. M, revolving horse-shoe magnet; A B, soft iron cores surrounded by wire spirals. When S is approaching to and opposite A, and N is approaching to and opposite B, the induced currents flow in the direction indicated by the arrows. When S is approaching to and opposite B, and N is approaching to and opposite A, they flow in the direction opposed to the arrows. In each case there is a momentary cessation of current when one of the magnet poles confronts A and the other B, and a maximum of current when the magnet reaches the position C, so that it is at right angles with the plane of the paper.

Wires connected the apparatus with an outer circuit, through which the currents could be conducted and utilized for any desired object, and in order to obviate the (for many purposes) inconvenient alternations of the currents, a commutator (current reverser) was introduced, by means of which the currents in the outer circuit could be rendered *continuous*, *i. e.*, obliged to flow always in the same direction. Their extremely rapid succession then enabled them for practical purposes to behave as one uninterrupted current. Fig. 27 enables the principle of Pixii's machine to be understood. In its construction, however, the magnet is placed below and not above the coils.

The drawback to Pixii's machine lay in the necessity (when a large size was required) of rotating an exceedingly heavy magnet, compelling the expenditure of much mechanical work, for which but a comparatively small return in the shape of electrical energy was made. Clarke and other inventors conceived the idea of making the bobbins revolve before the magnet, instead of the magnet before the bobbins, so that the heaviest part of the apparatus should remain at rest; and much saving of mechanical power was effected in this way. A small portable form of Clarke's machine is still frequently used for medical purposes.

Magneto-electric machines were next improved by constructing them with electro as well as with permanent magnets. In Wilde's machine, one of the best of the earlier kind, the steel horse-shoe magnets are quite small, and used merely to generate currents in a small electro-magnet of cylindrical shape, revolving between their poles, and called an *armature*. The induced currents in this armature are then carried by means of connecting wires through the coils of

[1] See Part III. Chap. iv.

two large fixed electro-magnets, known as the field-magnets, between whose poles another cylindrical armature revolves. The currents thus obtained are exceedingly powerful; but a great drawback to Wilde's machine exists in the large amount of heat it generates, which not only rapidly weakens the current, but makes its constancy a matter of impossibility.

The cylindrical armature used in Wilde's and in many magneto-electric and dynamo machines was invented by Dr. Werner Siemens, one of the four celebrated brothers whose scientific discoveries and appliances are so justly famous. Its utility consists in the fact that, owing to its shape, it is able to revolve in the most powerful part of the magnetic field, *i. e.*, exactly between the poles, thus combining high efficiency with great economy of space. The wire in a Siemens armature is wound lengthwise, like thread in a shuttle, and is enclosed in an iron sheath open at the sides, as represented in Fig. 28. The poles are not situated at the ends of this armature (or electro-magnet), but on the two faces (P P) of the iron sheath which have not been cut away. At every half-revolution of the armature the polarity is reversed, that which was a North-seeking becoming a South-seeking pole, and *vice versa*.

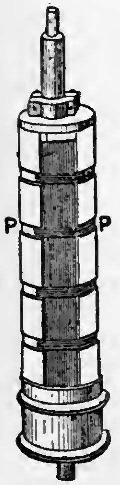

FIG. 28.—Shuttle-wound Siemens Armature.

The principle of the dynamo machines, shortly stated, consists in utilizing the residual magnetism left in the soft iron core of an electro-magnet as a current generator. Nearly all iron retains a faint remnant of magnetism when once it has been highly magnetized; and therefore an electro-magnet, not externally excited, but rotating as an armature between the poles of two much larger electro-magnets, first induces feeble currents in its own coil, and these being transmitted through the coils of the fixed magnets, render them also active, and consequently able in their turn to exalt the magnetism of the rotating armature by their reaction on it. The armature thus reinforced, itself induces and transmits more powerful currents, to be again strengthened in their passage through the fixed or *field magnets* (thus named because their work is to form a powerful magnetic field for the armature to revolve in), and by this system of continued action and reaction exceedingly strong currents can be obtained in an incredibly short time, and conducted into an outer circuit for use.

The name of dynamos was originally given to machines worked on this principle, because at first sight they appear to owe their electrical energy more directly to the mechanical power expended in rotating the coils than do the magneto-electric machines. Such is not in reality the case, however. Just as both kinds of machines derive their capability of generating electric currents from electro-magnetic induction, so, also, both kinds must have mechanical energy of some description, be it in the form of hand, horse, steam, or water power, expended on them in order to convert it into electrical energy; and it has now become common to include them all under the name of dynamos, distinguishing the two classes as magneto and self-exciting dynamos.

The principle of the self-exciting dynamo was simultaneously discovered by Siemens and a partner in the Siemens firm, Hefner von Alteneck, and by Wheatstone and Varley. Since its first appearance the Siemens machine has undergone various improvements. One of the latest types is represented in Fig. 29. It consists of two powerful flat electro-magnets, between whose poles is a rotating armature, not made on the plan of the original shuttle-wound Siemens armature,

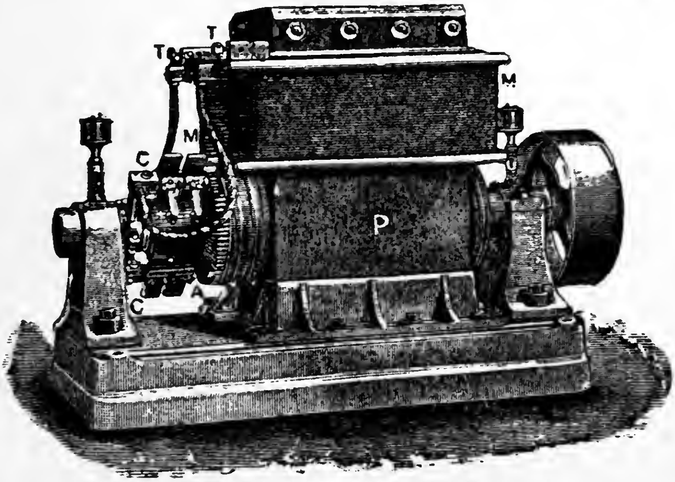

FIG. 29.—Siemens Dynamo (compound-wound). A, armature; M M, field-magnet coils; P, iron pole piece attached to near magnet (that of the far magnet cannot be distinguished); C C, commutator and collecting brushes; T T, terminal binding screws.

but on the same general principle as the Gramme ring, which gives its name to another typical dynamo machine.

The principle of this ring may be broadly understood by reference to Fig. 30. Suppose N and S to be the poles of a magnet between which a ring of soft iron, wound over with insulated copper wire, is revolving in the direction indicated by the large inner arrow A. Owing to the action of N and S, magnetism will be induced in the iron ring, and whatever portion of it is for the moment opposite N[1] will possess South-seeking, and that opposite S North-seeking magnetism, so that the ring itself acquires poles which remain sta-

[1] Not exactly opposite, however. The poles of the rotating ring will in each case be a little further forward in the direction of rotation than the poles of the field magnets, owing to the iron requiring time to attain its maximum state of magnetization.

tionary despite its own movement of rotation. In consequence of this, the currents induced by it in its surrounding coil will be such as to flow always in one direction between B, N, B′, and in the opposite direction between B, S, B′, as indicated by the small arrows placed near each convolution of the wire. The result of this will be a rise of potential from B past N to B′ through one half of the ring, and from B past S to B′ through the opposite half of the ring, so that the point of highest potential will always be in that turn of the wire opposite A, and the point of lowest potential in that opposite B. A current will therefore flow through a conductor whose ends are respectively in contact with these points of highest and lowest potential, just as a current will flow through any conductor whose ends are connected to the opposite poles of a galvanic battery. In the actual Gramme machine the ring is not made of one circular bar of soft iron, but of a number of iron wires bent into the required shape, in order to avoid the greater amount of self-induction which would take place in the former case, and which on account of the resistance it entails and the consequent large heat-generation, causes a great waste of energy.[1] The armature coils also are not continuous, as in the figure, but divided into sections, which are connected to each other in series, every one being also connected to a separate copper strip forming a segment of the commutator. The necessary contact between the points of highest and lowest potential and the conducting wires is brought about by means of wire brushes, or in large machines by thin copper plates, which are situated at these points, and which, as the ring revolves, rub against the copper strips already mentioned as forming segments of the commutator. This last is rendered necessary by the fact that a change of direction in the current takes place at B and B′ (see the reversed position of the arrows at these points), so that, unless special means were used to prevent it, the current sent through the outer circuit would be *alternating*. Through the action of the commutator, however, it is rendered *continuous*. The Siemens dynamo represented in Fig. 29 is also a continuous-current machine, but a large and important class of dynamos is made to produce alternating currents, and in these (in

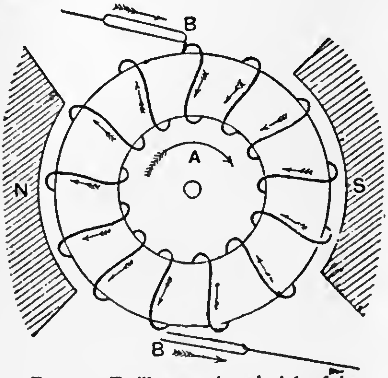

Fig. 30.—To illustrate the principle of the Gramme Ring.

[1] No armature cores, in fact, are solid. They are all made of wires or of thin insulated sheets of iron, to reduce as much as possible what are known as the "eddy" or Foucault currents.

which, of course, no commutator is necessary) the direction of the current is constantly reversed, often many hundred times in a second. Fig. 31 represents a simple form of continuous-current dynamo with a Gramme armature.

It must not be supposed that the dynamos above named are those in exclusive use now. They have been selected for mention partly on account of their historical interest, partly because they are still in wide use and favor. Beside the machines distinguished by having cylindrical and ring-shaped armatures, many are made whose armatures have the form of a drum, others that of a disc. All these are supposed to possess certain technical advantages, but the main principle of all is the same, and that is the one important thing for the

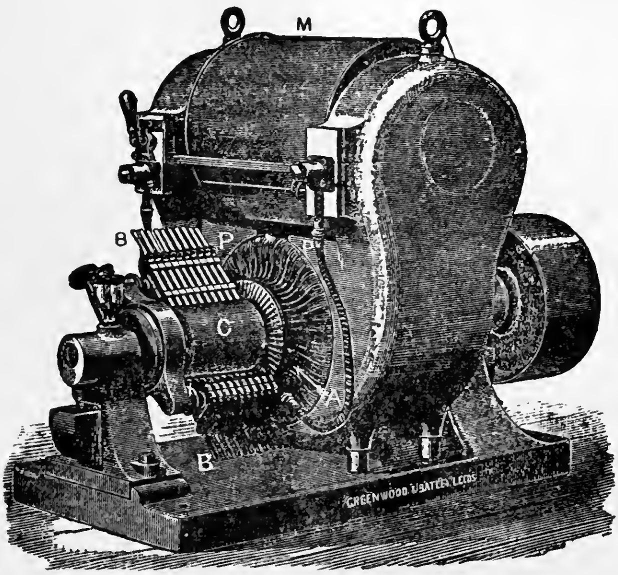

Fig. 31.—Simple form of Dynamo with Gramme Armature. M, coil of field magnet: P P, iron pole pieces; A, armature; C, commutator; B B, collecting brushes.

non-technical reader to grasp. Beyond this he will readily understand that what is wanted to make a good dynamo is a powerful magnetic field, a low resistance in the electric circuit, a great facility of magnetization (high magnetic permeability) in the armature cores and any magnetic portion of the machine, and as little waste of energy as possible through heating. These objects are accomplished in various ways by various makers, and since it is impossible that all can be equally well attended to in all dynamos, the same kind will not be found equally suited for every purpose. Each special class of dynamo will be best adapted to some special kind of work, and experience alone can assign to each that for which it is most fitted. It may be mentioned, however, that the suitability of dynamos to any particular purpose depends very much on the manner in which the magnet coils are wound. This may be in one of three ways—"series," "shunt," or "compound."

Series-wound dynamos send the whole of their armature current through the field-magnet coils, which are connected in series with the main circuit. These dynamos are used for arc lighting in series, and sometimes for charging accumulators.

In shunt-wound dynamos the terminals of the field-magnet coils and those of the main circuit are separately connected to the collecting brushes, so that the two circuits are in parallel and not in series. The magnet coils being made of very fine wire, offer a much higher resistance than the main circuit, receiving in consequence but a small proportion of the current; they are therefore said to act as a "shunt." Dynamos of this kind are used for charging accumulators, and in some systems of incandescent lighting.

Compound-wound dynamos have the great advantage of being self-regulating, because a constant potential difference is maintained at their terminals, so that the current in the outer circuit is inversely as the resistance. These dynamos are used for arc and incandescent lighting in parallel (viz., in systems where the current does not flow from one lamp to another, but to all separately), and in any case where much regulation is necessary.

The third class of machines to be considered is that of electro-magnetic engines, or, as they are usually called, *electro-motors*. These, as their name indicates, do mechanical work by means of electricity. We have seen that dynamos have mechanical work expended on them in order that they may turn it into electrical energy. In electro-motors the process is reversed; they turn electrical into mechanical energy, and that with far less waste than occurs in the analogous case of a steam-engine turning heat into mechanical energy; so that as a motive power electricity might ere this have remained sole master of the field, had it not been for the great expense till recently entailed by its use.

The constant and persevering efforts of inventors have, therefore, been directed as much to reducing the cost as to improving the construction of dynamos and electro-motors, with how large a measure of success the wide-spread adoption of electric lighting, and to a lesser extent of electric traction, sufficiently prove, while the growing popularity of electrical engineering as a profession shows with what confidence its future is regarded.

It is not necessary to enter into any detailed description of the construction of electro-motors, as they are so similar to continuous-current dynamo machines that any one of these can be used as an electro-motor;[1] only if it is so used, it must be driven by a current from an

[1] Nevertheless it is usually found better in practice to make a machine to be used

external source, not by its own current. The same machine cannot be used at the same time as a producer of both mechanical and electrical energy; it will give out either, but not both, and one must first be given to it. Fig. 32 represents a machine constructed purposely to be used as an electro-motor.

The currents generated by dynamos may be either of very high electro-motive force or of great strength (many ampères), or both, according to the purpose for which they are required and the consequent construction of the machine. For many purposes (such as electric lighting) it is preferable to use currents of a very high electro-motive force. This is much the same as employing a small volume of water at high pressure, instead of a large volume at low pressure; and, in fact, the term "electric pressure" is very frequently used by engineers. It is important to bear in mind, however, that this is merely a convenient mode of expression, and does not assert (as in the case of water) an ascertained fact. Currents of high "electric pressure," *i. e.*, of considerable electro-motive force (1000 volts and upwards), are attended with great risk; for if due precaution is not taken, they are dangerous to life, and should therefore never be carried into private houses, nor is there as a rule any need to do so. For any ordinary illuminating purposes a current of 100 volts is amply sufficient; and though along the main wires from a central lighting station it may be necessary to have a current of 2000 volts or more, by means of transformers this can be reduced on entering a house to 100 volts. Transformers are only an adaptation of induction coils in which the usual process is reversed, and instead of a large current of low electro-motive force inducing a small current of high electro-motive force, the exact opposite takes place. Transformers can, however, only be made use of with alternating currents, for it will be remembered that secondary currents never arise except when the strength of the primary is changing. Consequently, if the latter were continuous, secondary currents and any apparatus depending on them would be impossible. Where transformers are used, the electric-lighting circuit of each house is complete in itself, and is not directly connected with the main circuit, the latter merely inducing in the secondary circuits the currents necessary for their purpose.

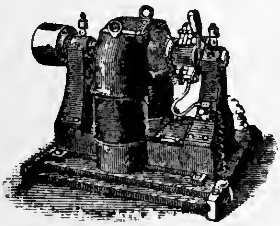

FIG. 32.—MOTOR.

as an electro-motor specially for that purpose, as slight differences of construction can then be introduced which render it more efficient.

CHAPTER II.

ELECTRIC LIGHTING.

Electricity a light producer—First exhibition of voltaic arc—In what it consists—Size increases with E. M. F. of current—Vividness—Use in lighthouses—Cause of the light—Unequal consumption of the carbons—Consequent unsteadiness of light—Means of rectification—Variety of arc lamps—Illuminative power—Electric candles—Incandescent light—Its principle—Difficulty originally encountered in construction of incandescent lamps—Obviated by improved vacuum—Description of Edison's and Swan's incandescent lamps—Holders—Generation of electric-lighting currents—Central lighting stations—Street illumination—Indoor illumination—Use of accumulators—High-potential currents necessary in main wires—Importance of careful insulation—English mode—American mode—Imperfection of American installations—Safety of electric lighting if properly carried out—Advantages of electric light—Various appliances.

THE electric spark, the electric glow, and the luminous discharge through rarefied gases, all made known (and lightning did so long before them) that electricity is a light producer. The possibility of using it for ordinary purposes of illumination was not understood, however, till the beginning of the present century, when Sir Humphry Davy first exhibited the "voltaic arc" in public at a meeting of the Royal Society in 1810. He employed for the purpose an exceedingly powerful battery of over 2000 elements, and though the beauty and brilliancy of the light were beyond all question, the expense of its production relegated it for a considerable time after this to the region of experiment only. The arc produced by Davy, and of which so much has been heard since, consists of an intensely vivid band of light passing between two carbon pencils, which form part of a powerful voltaic circuit. These pencils, of which an illustration is given in Fig. 33, are first brought into momentary contact and then drawn a short distance apart. A current of sufficient electro-motive force is able to overleap this gap, but in doing so it has to overcome a very high resistance, and the consequence is an outburst of heat and light of extraordinary intensity. The higher the electro-motive force, the greater may be the distance between the carbon points, and the more vivid of course will be the light. It is too vivid, in fact, for many purposes; it dazzles, and for the interior of most public buildings, churches, hotels, theatres, etc., as well as for private houses, the incandescent mode of lighting, to be presently described, is far preferable. For open air illumination, however, the arc light presents great advantages, not the least of which is its comparative

FIG. 33.—Carbon Pencils used for the production of the arc light. the positive pencil showing the concave form assumed owing to its more rapid consumption.

inexpensiveness; and it is unrivaled in one department of the highest importance, viz., that of lighthouses, where its object is not so much to render other things visible as to be seen itself; it was in fact for them that it was first brought into use. In the search-lights employed for naval and military purposes, its great intensity renders it also specially suitable.

The main cause of the light appears to be the incandescence of minute particles of carbon, which are carried in two incessant streams between the carbon pencils, the principal direction being always from positive to negative. On account of the great affinity of carbon at a high temperature for oxygen, combustion of the pencils takes place even when they are exposed to rarefied air, the positive carbon consuming nearly twice as fast as the negative.[1] Consequently the distance between the two pencils is continually increasing, and unless means of rectification are used, soon becomes too great to allow the current to overleap it, so that the light, after becoming fainter and fainter, goes out altogether. Numerous ingenious automatic contrivances have been devised to obviate this difficulty, and keep the carbons at an equal distance apart; and these, combined with the great steadiness of current which is attainable by the use of the modern compound-wound dynamos, have almost completely done away with the flickering and inconstancy of the earlier arc lights. If, therefore, such inconveniences are suffered from in modern days, it is because the installations are in some way less perfect than they could be.

The variety of arc lamps is very great, but their principle having been described, it is needless to go into technical details, which would be wearisome to the general reader. Suffice it to say that the principal aim of inventors is to increase the steadiness of the light by keeping the distance between the pencils as constant as possible, and by using in their construction the purest carbon obtainable. The illuminative power of an arc lamp depends of course on the size of the arc, and this partly on the quantity of current, so that for lamps which are intended to light up a large area, currents of many ampères are needed.

Electric candles, which are a form of arc lamp, must not go unmentioned. The first was the Jablockoff, so called from the name of its inventor. It consists of two perpendicular rods of carbon, united at the top by a very thin bridge of the same substance, below which they are divided by a layer of some insulating material, usually plaster of Paris. When the current passes, the carbon bridge is rapidly consumed by the intense heat developed, and a voltaic arc takes its place,

[1] It must not be supposed, however, that combustion is the cause of the light, as in an ordinary oil or gas lamp, for the arc light can be quite satisfactorily produced in a vacuum or under water.

which melts the insulating material as the carbons gradually burn away. In order that their consumption may be equal, alternating currents are used, so that the same carbon is alternatively positive and negative. The Jablockoff candle is equal in illuminative power to ten, twenty, one hundred or more ordinary candles, according to its size. It was at one time in great demand, especially in France, but was never found altogether satisfactory, and has therefore almost fallen into disuse. Later and better forms of electric candle have been devised, using air as the insulating layer, and with other improvements; but they are neither so simple as the regulated arc lamp, nor do they give so high a proportion of light for the current expended on them, and they are therefore not much employed.

On account of the unsteadiness and too great brilliancy of the arc lamps, electric lighting for domestic and most indoor purposes would never have become general had there not existed another and in this respect more satisfactory method, known as the *incandescent*. In this no gap is formed in the circuit, but it includes substances of very high resistance (such as carbon or platinum), which are raised to a white heat by the passage of the current. Almost every reader is acquainted with the beautiful little lamps known by the names of Swan and Edison, whose light for all ordinary purposes leaves nothing to be desired either in softness or brilliancy, yet hardly ten years have elapsed since their first appearance. The possibility of "incandescent" electric lamps was indeed known long before this, but an insuperable difficulty seemed to lie in the way of their construction, for a material was needed combining two qualifications which had never been found united in the same substance. The first was that it should not, when raised to a high temperature, have an affinity for oxygen; and the second, that under the same circumstances it should not melt. Carbon possessed the latter of these requirements, and platinum the former; but no vacuum had ever been made sufficiently perfect to render carbon incombustible, and platinum could not of course be induced to raise its melting-point, already higher than that of any other metal. The perfecting of the mercurial air-pump at length rendered it possible to produce a degree of exhaustion, in which carbon remained incombustible for want of oxygen to combine with, and from that moment the future of the incandescent lamps was secured. Inventors by the score sprang into the field, each with a lamp which some special qualification was supposed to render superior to all others, but the most successful competitors were Swan in England, and Edison in America, soon followed by Lane Fox in the former, and Maxim in the latter country.

The principle of the incandescent lamps is the same, whatever differences of detail there may be in their construction. It consists in raising a thin carbon filament, enclosed in a glass vessel exhausted to the pitch of about the millionth of an atmosphere, to a state of incandescence, by the passage through it of an electric current. The carbon filaments are made of different materials by different constructors. Edison uses bamboo fibres, 0.04 inch in diameter and about five inches in length; Swan selected cotton thread, which he soaked in sulphuric acid, thus transforming it into a species of parchment; and this preparation is adopted by the Edison-Swan Company. Edison's bamboo fibres are carbonized by being placed in U-shaped molds and baked in ovens. Swan's thread fibres, after being treated with the sulphuric acid, are bent into the desired form, and enclosed in hermetically-sealed crucibles filled with coal-dust, which are subjected to the requisite heat. These carbon filaments are fastened to platinum wires, which are fused into exhausted glass vessels, and their free ends connected by appropriate adjustments to the wire conveying the current. In order to ensure equality of resistance, the carbon filaments are made of exactly the same thickness throughout, which is secured by placing the carbon filaments in a hydro-carbon atmosphere, and passing a current through them till they glow. A deposit of carbon on the filaments is the result, the deposit being thickest where the carbons are thinnest, and therefore hottest. This operation is called "flashing." At the points of junction with the platinum wires, however, a great increase of thickness is necessary in order to prevent the melting of the platinum by the intense heat developed.[1] Fig. 34 represents an Edison incandescent lamp.

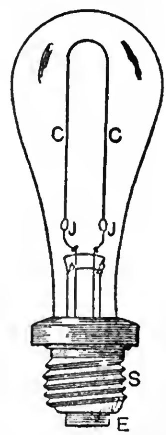

FIG. 34. — Edison's Incandescent Lamp. C C, carbon filament; J J, junctions of the carbon filament with platinum wires; *p p*, platinum wires by means of which current is conveyed to the carbon filament; S E, metallic screw and end forming the terminals of the lamp, contact being automatically made with the similar parts of the socket into which the lamp is fitted.

All incandescent lamps need special holders by whose means the necessary connection with the conducting wire can be set up and maintained.

The currents for electric-lighting purposes are generated by dynamos, which are driven by steam or gas engines, or when practicable by water power. For every eight or ten lamps of sixteen candle power each, current is required which necessitates an expenditure of mechanical work equivalent to one indicated horse power, so that the dynamos and engines must be in proportion to the amount of lighting to be done and the consequent current needed.

[1] It is erroneous to suppose that the electric light is unaccompanied by heat. That of the voltaic arc is the most intense known, and we have seen that even platinum is unable to withstand the high temperature to which the passage of the electric current raises it. Nevertheless, on account of the small volume of the arc, and of the incandescent carbon filaments, they give out, though intensely hot themselves, a very minute amount of heat compared to that from gas and candle flames for the same amount of light.

The arc lamps used in street lighting may be connected to the main circuit either in parallel or in series, according to the system employed. If they are in series, the current passes through each one in succession, and, unless special provision is made, they must all be turned on or put out together. In some systems, however, notably the Thomson-

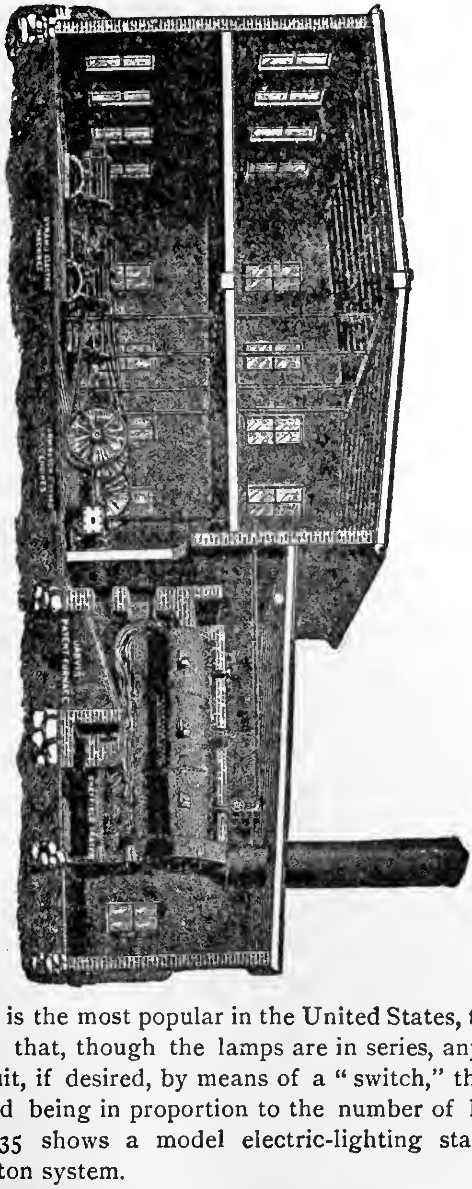

Fig. 35.—Model Electric-Lighting Station on the Thomson-Houston System.

Houston, which is the most popular in the United States, the machines are so regulated that, though the lamps are in series, any one can be cut out of circuit, if desired, by means of a "switch," the amount of power consumed being in proportion to the number of lamps maintained. Fig. 35 shows a model electric-lighting station on the Thomson-Houston system.

The circuits which supply domestic, and, in fact, all indoor illumination, are often, by means of transformers, or of secondary batteries, kept distinct from the main circuit, the latter being merely used to feed them. In the case of transformers this is done by induction, as was described in Chapter I., the apparatus being carefully enclosed in a locked receptacle, so that no inmate of the house in which it is placed can have access to the dangerous currents. In the case of secondary batteries, or *accumulators*, as they are very frequently called, the charging is done by the main circuit current, from which they are afterward disconnected and made to do their own work, to be reconnected and recharged when necessary. There are two objections to the use of accumulators, however—their cost is considerable, and they constantly require skilled attention. On this account, when they are used to supply town dwelling-houses, a number are placed together in a sub-lighting station, and each one is connected during the time the current is required to the house which it feeds. When it has to be charged, it is joined in series with the other accumulators belonging to the same group as itself, and this group is then connected to the main circuit for the requisite number of hours.[1] The advantage of this arrangement is that the dynamos which supply the main currents can be utilized to charge the accumulators during the daytime, and since these then feed their own circuits, the installation at the central station may be much smaller than if it had to provide directly all the current required during the night hours, as is the case when transformers are used. Every lamp for indoor illumination can be, and usually is, supplied with a separate connection to the conducting wire, which can be made or broken at pleasure, so that the lamp may be lighted or put out independently of any other in the same building. A great number also are provided with safety fuses, viz., a piece of wire attached to the lamp, and through which the current must pass. Should the latter attain an undue strength, the fuse melts, the circuit is broken, and the lamp goes out, so that all danger from overheating is obviated.

In order that the distribution of electric energy from the central lighting station may be carried out as economically as possible, currents of very high electro-motive force (usually about 2,000 volts) are conveyed by the main wires, which it is therefore necessary to insulate in the most careful way. In England they are surrounded by layers of insulating material, and buried underground. In America they are often carried overhead, but this system is open to very great objection, as a high wind or heavy fall of snow may break down the wires, and they are then exceedingly dangerous, both on account of the high

[1] Of course accumulators cannot be charged except by continuous-current dynamos, as the chemical decomposition necessary to the storage of electric energy could not be carried on with alternating currents, which would undo the work as fast as it was accomplished.

potential currents they convey, and of their own weight. It is to be observed, that though electric lighting is far more extensively used in America than in England and Europe generally, the technical perfection of the installations is not so good. Insulation is not sufficiently attended to,[1] the neighborhood of gas-pipes and mains to the wires is not avoided as it should be; so that in case of overheating of the latter, danger of explosion occurs; and the system of overhead wires, unsightly to the last degree, gives rise to inconvenience and peril, which till lately met with less consideration than should have been the case. In New York, however, a regular rebellion has taken place against the overhead system, the wires have been hewn down in all parts of the city, and their place is being supplied as fast as possible by underground cables.[2] So many accounts of fatal accidents (numbers of which are untrue) from electric-lighting currents have been telegraphed across the Atlantic, that timid persons may well shrink from the idea of seeing them come into general use in England. There is no real occasion for alarm, however. If the conducting wires are thoroughly insulated, so as to render the touching and handling of them impossible, very carefully joined where joins are necessary, and thick enough not to be overheated by the strongest current they would ever be called upon to convey, no possible danger can occur. If these precautions are neglected, the consequences may be disastrous, though not more so than if due care is not taken with those equally perilous agents, gas and steam. An electric light installation set up by competent electrical engineers, allowed to provide all those safeguards which they know to be necessary, is perfectly harmless; but if cheapness is made the first desideratum, and bad workmen and bad materials are employed, the result is as unsatisfactory and dangerous as a similar mode of proceeding would be if followed by gas and railway companies.

The advantages of the electric over other kinds of artificial light are in many respects very great. In the first place, it is much healthier; for it does not, as they do, take up oxygen and give out carbonic acid gas. Then, it does not perceptibly raise the temperature of an enclosed space, so that a room or building lighted by it does not become filled with overheated air. Again, owing to its near approach to the composition of sunlight, colors are clearly distinguishable by it, which are confused with one another or altered in hue by gas or candle-light; and for the same reason, photographic and other chemical work can be carried on by its means when they would otherwise be impossible. The electric light is, in fact, particularly rich in

[1] It is just to say, however, that owing to the much greater dryness of the climate, insulation is far more easily carried out in America than in England, and a system which would be dangerous in the latter country might be perfectly safe in the former.

[2] January, 1890.

chemical rays; and the arc light, owing to the preponderance of violet in its spectrum, gives a cold and rather ghastly appearance to persons and things. This is not the case with the incandescent lamps; and, in fact, when sunlight and any kind of electric light are seen at the same time, the latter is found to have by comparison a reddish hue. The weird effect of the arc light is probably in great part due to our being accustomed to the very red tint of gas; and, of course, where the two illuminants are seen close together, as frequently happens in London, the result is exceedingly unpleasant.

Besides its extensive adoption on land and for lighthouses, where its superiority over any other kind of illuminant is incalculable, the electric light is also much used now on board ship, as well for ordinary purposes as for signaling; and it is of interest to note that by its means the Suez Canal has been rendered navigable by night, its passage during the hours of darkness being permitted to all vessels carrying electric search-lights, arranged according to the regulations laid down by the Canal Company. The use of electric search-lights on board warships has already been referred to, and their importance can hardly be over-estimated now it is acknowledged that nets are of little if any protection against torpedoes, so that the only safety from these formidable engines of destruction lies in being aware of their approach. This can only be ensured at night by throwing powerful streams of light in every direction from which danger is to be apprehended, and the intensity of the arc light makes it specially suitable for this purpose, rendering the detection of torpedo-boats a matter of comparative ease.

Among the minor uses to which the electric light has been put, the production of very beautiful scenic effects in theatres may be mentioned; and it has even been made to contribute to the personal adornment of the actors. "Electric hairpins" are described in "Electricity in the Service of Man."[1] They are simply miniature glow lamps arranged so as to simulate gems of various colors, and supplied with the necessary current by a tiny battery enclosed in a gutta-percha box, small enough to be concealed in the hair or head-dress. Another very ingenious contrivance is mentioned in the same work, and consists of an apparatus enabling a faint light like that of the will-o'-the-wisp to play about the heads of those wearing it. The frequent variations of intensity which are necessary in theatrical lights, render indispensable contrivances enabling any particular lamp, or whole series of lamps, to be put in and out of circuit as desired; and, in fact, such arrangements are required in all indoor illumination, as the number of lamps in use in any building is constantly altering. If many lamps are put out of circuit at the same time, it is necessary, unless compound-wound, *i. e.*, constant potential-

[1] P. 562.

difference, dynamos are supplying the current, to increase the resistance encountered, as the current would otherwise be too powerful for the remaining lamps. To accomplish this, arrangements are made by which resistance-boards or coils can be included or cut out of circuit at will. The latter are merely wire coils usually made of German silver; the former consist of a number of parallel carbon rods fixed on a wooden board, any or all of which can be included in circuit as desired.

A very curious appliance of the electric light is mentioned in *The Electrician* for January 10, 1890, viz., its being used to lure fishes and submarine animals into a trap employed in the deep-sea investigations undertaken by the Prince of Monaco. The light and the battery supplying it were placed in a wire trap, and in order to keep the box in which the battery was enclosed from being crushed by the enormous pressure of water, it was connected with an air balloon in such a way that air could pass from one to the other. As the pressure on the balloon increased in its descent through the water, air was forced from it into the box, thus providing the interior of the latter with an equal and contrary pressure to that exerted on its exterior, the balloon itself gradually diminishing in size till it was reduced to a fraction of its original volume, and expanding again when the apparatus was raised and the pressure of water decreased. The experiment was so successful that the Prince hopes on his next expedition to obtain photographs of the ocean bed by means of the electric light.

For purposes of electric lighting and transmission of power, it is obviously necessary that both supplier and consumer should be able to gauge, with fair exactitude, what amount of electric energy is used; but the measurement cannot be accomplished in so simple and certain a way as the measurement of gas consumption, for instance. The latter depends upon quantity only, but the measurement of electrical energy depends upon the electro-motive force (or pressure), as well as on the strength of current. If the former were to fall below its right value, the consumer would not be getting his due proportion of energy, though the current strength might be fully maintained. The meter employed, therefore, ought to be a *volt-meter* or measurer of electro-motive force, as well as an ampère or *am-meter*, measurer of current strength. It is not easy to combine these two requisites in a simple and efficient form, and many inventors have employed their ingenuity in this direction, without as yet obtaining a perfectly satisfactory result. The best appears to be given by the clock-meter of Professors Ayrton and Perry, whose most important constituent is a good clock, the works of which are electrically connected to the wires conveying current to and from the house, in such a way as to be affected both by its pressure and strength. The clock consequently loses in exact proportion to the amount of energy consumed. If, however, a constant electric pressure between the house mains can be secured, it is sufficient to measure only the quantity of current that passes.

CHAPTER III.

TRANSMISSION OF POWER BY ELECTRICITY.

Definition of power—Units of power—Various agents for the transmission of power—Its importance—Loss incurred—Advantages of electricity as a transmitter of power—Its probable universal adoption—Requisites for the transmission of power by electricity—Electric railways—Telpherage—Attempts to utilize electricity for road traffic—Other applications—Electric launches.

BY the term "power" engineers understand the rate of doing work. The transmission of power therefore means not simply the transmission of work, but of a given amount of work in a given time. The ordinary unit of work in England is the *foot pound*, viz., the amount of work done in raising one pound to the height of one foot. For engineering purposes horse-power, which is equivalent to 33,000 foot pounds per minute, is often used as the unit of power; and in electrical engineering the unit of power is the Watt, which equals 44¼ foot pounds per minute, so that 746 Watts are equivalent to one horse-power.[1]

Power may be transmitted by various agents. We may pull a handle connected to a bell wire, and thus ring a bell in a distant room; the wire is here the transmitter of power. Or there may be no bell wire, but by pulling the handle we may cause the compression or rarefaction of air in a tube, at the other end of which the bell will ring. In this case the transmitter of power is the air. Or the bell may be an "electric bell," and by the pressure of our hand on a button in the wall we may start an electric current, by means of which the ringing is accomplished; electricity then being the transmitter of power. It is the transmitter only, however, not the source. That, in each of the three cases mentioned, is the human hand, whose action in pulling or pressing the bell handle, originates the power transmitted by the wire, the air, or the electric current.

Even from such a trivial example as the ringing of a bell, it is easy to see what importance attaches to the transmission of

[1] Electrically defined, the Watt is the power developed in a circuit through which a current of one ampère is flowing, and which has a potential difference of one volt between its ends.

power, and what saving of time and labor it may enable us to effect. Because the mechanical action of pulling or pressing a bell-handle can be transmitted to a distance, a slight exertion and a small bell will suffice; but if we could only ring the bell at the spot where we ourselves might be, a much larger bell and far greater exertion would be necessary in order to attract the attention of those at a distance.

In all transmission of power some loss occurs. We never get back exactly the amount of power originally expended, and where the distance is great the loss is often very considerable. It is less where electricity is employed than in any other case, however, and consequently now that dynamos and electro-motors are so much less costly of construction than they were a few years ago, electricity bids fair to become the cheapest, as well as the most rapid, cleanest and most easily controlled transmitter of power known. It has not, indeed, yet been applied to great distances and large power; but whatever initial difficulties there may be in thus utilizing it, they are not of such a formidable nature as to prevent, or even long retard, its widespread adoption; and not scientists and electrical engineers only, but the foremost statesman in England [1] has ventured to look forward to the time when noisy and crowded factories will be abolished, and each workman supplied at his own house with the power necessary for his work, distributed from a central station as electric-lighting currents now are. In fact, with very little increase of cost and material, the same station would serve both purposes. The currents are not wanted for lighting during the daytime; and though, where accumulators are used, they must be charged, this would not occupy all the dynamos at a central station, nor any of them during a whole day, so that, at no very distant future, we may contemplate the establishment of centres which shall supply each household with light during the hours of darkness, and with power during the day. This system is already extensively adopted in America, to supply workshops where only small power is required, such as those of tailors, shoemakers, watchmakers, etc., but it has not yet been attempted on a large scale.

The requisites for electrical transmission of power are—

1. Mechanical power of some kind to drive the dynamos.[2]

2. The dynamos or current-generators themselves.

3. An electro-motor or motors, placed where the supply of power is required.

4. An electrical connection between the dynamos and the electro-

[1] Lord Salisbury in his speech at the First Dinner of the Institute of Electrical Engineers.

[2] It is not intended to state that the transmission of power by electricity can only take place by means of currents generated by dynamos. Batteries may be used; but for reasons already pointed out they are unsuitable, except when (as in telegraphy) the power to be transmitted is very small.

motors, unless accumulators are used, when such connection is of course unnecessary, and the dynamos are employed for charging.

The driving of the dynamos is generally accomplished either by water-power or steam. Wherever the former is available it is the best and most economical to use, and the continual regret of electrical engineers is the amount of energy running to waste in our streams and rivers, their dream for the future being that as electrical transmission of power becomes better understood and more easily available over long distances the water-power of every country may be found sufficient for its needs. Dynamos and electro-motors have been described in a previous chapter, and, with regard to the connection between the two, it varies according to the nature of the work to be performed, and with other local and technical causes.

The most important use to which electricity as a motive-power has been put is that of traction. Electric railways, or, more correctly speaking, tramways, as they are used only over short distances and for light traffic, are becoming well known, though not yet common. The motors are usually placed under the floor of the cars, and are supplied with current either through the rails on which the cars run, or by separate underground conductors, or by overhead conductors, as in Fig. 36; or they may be driven by accumulators, which in some

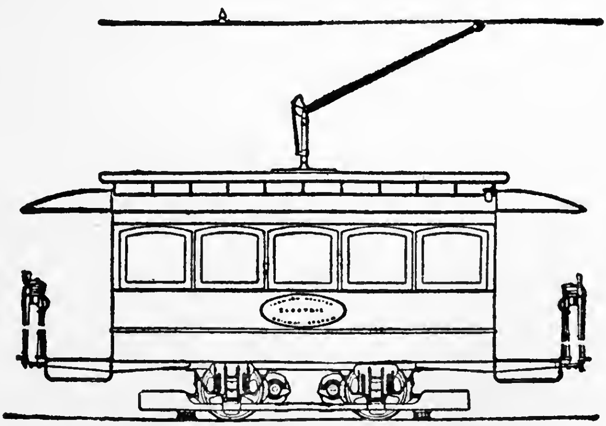

FIG. 36.—Electric Tramcar supplied with current by overhead conductors.

ways simplifies matters, as the rails need not then be insulated, and each car can be independent of its fellows. In other respects this system has disadvantages; the weight of the accumulators, which of course must be carried by the cars, being one, and the double transformation of energy they entail being another, as more waste is thereby necessitated.[1]

[1] Where accumulators are employed, mechanical energy (that used to turn the dynamo armatures) must first be converted into electrical energy, then the latter changed in the accumulator to stored-up chemical energy, which on being liberated is

The telpherage system, formerly used for the transport of goods only, but now beginning to be employed for passengers also, is specially suitable and economical for hilly country, and was introduced by Professors Ayrton and Perry, and the late Professor Fleeming Jenkin. In this system the traffic is carried on overhead, the conductors and trucks being suspended from poles erected about fifty yards apart. The conductors sometimes consist of two steel cables fixed one above the other, the trucks being suspended between them, and the upper cable bearing most of the weight. More usually, however, there is only one steel cable (as in the passenger telpher line at the Edinburgh Exhibition), by which the whole weight is supported. The trucks are provided with wheels through which, as they run along the conductors, the necessary current is supplied.

Attempts have been made to utilize electricity for ordinary street traffic, as well as for railways. In this case the motors which propel the vehicles are of course driven by accumulators, and success has been attained for short distances and light weights;[1] but for long distances, difficulties occur through the necessity of exchanging the exhausted accumulators for fresh ones; and when the cart or carriage is heavy, it is impossible to stop it with the rapidity often necessary in crowded streets. This difficulty arises from the increase of weight occasioned by the use of large accumulators, which gives too great a momentum to the vehicle.

Electricity has been made useful for locomotion in mines, for boring rocks, for lifts, for cranes, for brakes (the Westinghouse brake being familiar, at least by name, to all readers), and for driving machinery in factories.

Electrically-propelled ships have not been attempted on a large scale, but many electric launches are made, and found to answer exceedingly well. Their chief inconvenience lies in the fact that owing to their motors being driven by accumulators, they cannot go far from the charging station, unless indeed (as has been done on the Thames) sub-stations are placed at intervals on the line of route, so that exhausted accumulators can be replaced by fresh ones when necessary. The most recent application of electricity to naval purposes has been independently made by the French and Belgians, in submarine electric launches or torpedo boats, recalling on a small scale the marvelous vessel in Jules Verne's "Twenty Thousand Leagues under the Sea."

transformed once more into electrical energy, and then through the electro-motor back into mechanical energy. Where the dynamos supply the motors directly two transformations only take place, from mechanical into electrical energy in the dynamo, and from electrical into mechanical in the motor.

[1] An electric dogcart, made for the Sultan of Turkey in 1888, gave its imperial owner so much satisfaction that he has since ordered another.

The various uses to which electricity as a motive power has been put, have now been enumerated, but there is one to which neither it nor any of its rivals has yet been successfully applied, but which, nevertheless, we can hardly help regarding as probably one of its important functions in the future—this is aërial navigation. If our descendants are to travel in balloons, it will certainly be through the agency of electricity; and as the various electrical engines become more and more perfected, we can hardly doubt that in time a sufficiently light means of storing electric energy will be devised to make that dream of past ages—a flying machine—an actual reality.

CHAPTER IV.

THE ELECTRIC TELEGRAPH.

Early suggestions for using electricity and magnetism as a means of communication—Volta's and Œrsted's discoveries the foundation of modern telegraphy—Number of inventors who have contributed to its perfection—Wheatstone and Cooke's telegraph—Discovery of the "earth-circuit"—Introduction of the "translation" system—Recording and non-recording instruments—Morse's services to telegraphy—His embosser and ink-writer—The Morse key—Speed of transmission of messages—Hughes printing telegraph—The Morse sounder—Submarine signaling—The syphon recorder—Manner of conveying and insulating overland wires—Submarine cables—Duplex and quadruplex telegraphy—Telegraphic currents generated by batteries.

IT seems that the first really practical suggestion for using electricity as a means of communication, was made by the anonymous author of a letter to the *Scots Magazine* in 1753. The suggested apparatus, though cumbrous and complicated according to modern ideas, was very ingenious, but there is no record of its having been actually used. The writer, and such of his readers as took any interest in the subject, were doubtless of opinion that at any rate the idea was an entirely novel one, but in this they were to some extent mistaken. Though nothing was known about "current" electricity until the end of the eighteenth century, there had been vague ideas long before then that magnetism might be in some way utilized for purposes of communication. About 1750 a certain Joseph Glanvil, rector of Bath, who, we are informed, was a "learned writer upon abstruse and mystical subjects," wrote as follows in a treatise entitled "The Vanity of Dogmatizing," and in which he speaks of "supposed impossibilities which may not be so."

"That men should confer at very distant removes by an extemporary intercourse is a reputed impossibility; but there are yet some hints in natural operations that give us probability that 'tis feasible, and may be compassed without unwarrantable assistance from demoniack correspondence. That a couple of needles equally touched by the same magnet, being set in two dials exactly proportioned to each other, and circumscribed by the letters of the alphabet, may effect this 'magnale' (*i. e.*, important result), hath considerable authorities to avouch it. The manner of it is thus represented. Let the friends that would communicate take each a dial, and having appointed a time for their sympathetic conference, let one move his impregnate needle to any letter in the alphabet, and its affected fellow will precisely respect the same. So that would I know what my friend would acquaint me with, 'tis but observing the letters that are pointed at by my needle, and in their order transcribing them from their sympathized index as its motion directs, and I may be assured that my friend described the same with his, and that the words on my paper are of his inditing. Now, though there will be some ill contrivance in a circumstance of this invention, in that the thus impregnate needles will not move to, but avert from each other (as ingenious Dr. Browne hath observed), yet this cannot prejudice the main design of this way of secret conveyance; since it is but treading counter to the magnetic informer, and noting the letter which is most distant in the abecedarian circle from that which the needle turns to, and the case is not altered. Now, though this desirable effect possibly may not yet answer the expectations of inquisitive experiment, yet 'tis no despicable item, that by some other such way of magnetic efficiency it may hereafter with success be attempted, when magical history shall be enlarged by riper inspections; and 'tis not unlikely but that present discoveries might be improved to the performance."[1]

Could Joseph Glanvil's spirit revisit us now, he would see his expectations more than fulfilled, though it has not been by "riper inspections of magical history," but of natural science, that the "reputed impossibility" has become possible. Forty years after the treatise "On the Vanity of Dogmatizing" saw the light Volta had made his first battery, and twenty years later still came the announcement of Œrsted's famous experiments on the action of electric currents on the magnetic needle. These two discoveries are the foundation-stones of our modern system of telegraphy, which would be impossible without a steady current, as distinguished from the momentary rush of a discharge, and to which the deflections of the magnetic needle, under

[1] The above curious passage is quoted from a letter by the Rev. Canon Jackson of Leigh-de-la-Mere, Chippenham, the well-known antiquarian, to the *Bath Chronicle* in October, 1890.

the influence of electric currents, contributed a code of signals far superior to any which had previously been attempted with electricity.

So many scientific inventors have aided in bringing the electric telegraph to its present degree of perfection, that it would be impossible in the short compass of a chapter of the present volume even to name them all. The first really workable telegraph introduced into England was that of Wheatstone and Cooke, who at first employed five needles and as many wires to transmit their signals, but soon finding the cost and inconvenience of this method rendered its general adoption impracticable, they reduced the number of needles to two and finally to one, whose deflections to the right and left were so combined as to represent all the letters of the alphabet. In all the earlier telegraphic circuits it was considered necessary to have a return wire, but in 1838 Steinheil discovered that this could be dispensed with, and that if the two ends of the conducting wire were connected to earth, one at the sending, the other at the receiving station, the earth itself would play the part of the return wire. This discovery of the "earth circuit" was of the greatest practical importance, owing to the reduction in cost which it brought about.

Another very important improvement in the construction of electric telegraphs, is the system of "translation," which was introduced by an Englishman, Edward Davy. The principle consists simply in cutting up one long circuit into a number of short ones, which can be automatically connected whenever a signal is transmitted. The advantage of this system is, that even on a long circuit a weak current may be employed, as it will only have a comparatively short distance to traverse before its work is taken up by another.

The telegraphic instruments in modern use may be divided into two classes, recording and non-recording. To the former (whose signals are merely momentary and leave no after-traces) belong the needle and dial telegraphs and the sounders. To the latter belong the embossers, ink-writers, and type-writers. In international telegraphy and in the English Post-Office, Morse's instruments, of which some are recording and some non-recording, are almost exclusively used, and a slight description of them will therefore be given. Their inventor, Morse, who received considerable sums of money from various nations, in recognition of his services to international telegraphy, was an American, and his first experiments in the direction in which he afterward became so famous, were made as early as 1834, when he had already twice visited Europe. He labored at first under the disadvantage of very inadequate electrical knowledge, and, indeed, his mind was originally turned to what became his life-work by the accidental acquaintance made on one of his return voyages to America, with a fellow-traveller, Professor Jackson, of Boston, who was engaged on electrical experiments. At a later period Morse was indebted to his subsequent partner, Leonard Gale, for various suggestions as to the chemical part of his work.

Morse's embossing instrument leaves a permanent record of the message sent by indentations on a slip of paper. These are made by means of a small electro-magnet with a movable armature, to which is attached a hard-pointed piece of metal. Whenever a current passes through the instrument the armature and stylus are drawn forward, and the latter brought into contact with a slip of paper, unrolled and passed on by clockwork. When the current is interrupted, the armature and stylus return to their former position, to be again drawn forward as soon as a current is set going. In this way a series of scratches is made on the paper, the marks being longer or shorter according to the length of contact, and divided by spaces varying with the time of interruption of the current. The short marks are known as dots, and the longer ones as dashes, and by suitable combinations of them all the letters of the alphabet, the numerals, punctuations, and various signs are expressed in a system of signals, known as the Morse code, which is now almost universally adopted in Europe and America.[1] Morse's ink-writer, which is in most general use, is on the same plan as the embosser, but the place of the stylus is taken by a small disc kept constantly wetted with ink, by means of a suitable mechanical arrangement, so that ink-marks instead of scratches are impressed on the paper.

The incessant interruptions of current necessary in the Morse and in all telegraphic instruments, are brought about by means of a commutator or key, by which the operator closes and opens circuit at will. The Morse key is simply a brass lever kept in position by a spring S, as shown in Fig. 37. When the operator presses down the button B, he

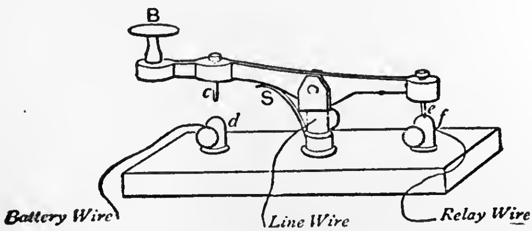

FIG. 37.—The Morse Key.

causes *c d* to come into contact, and by their means sends a current from the battery into the line wire. When B is not pressed down, *e f* are in contact as in the figure, and a current coming along the line passes round the relay electro-magnet (see Fig. 38) and works the relay tongue (*a*). This closes the circuit of a local battery, which sends a sufficiently strong current round the electro-magnets of the receiving

[1] The Morse code is used in the needle telegraphs also, an inflection to the left representing a dot, and one to the right a dash.

instrument to pull down the lever of the embosser or ink writer, an operation requiring too much force to be accomplished by the weak current which comes along the line. Polarized relays, *i. e.*, relays in which the core of the electro-magnet is formed of a steel magnet whose poles are not reversed by change of direction in the current, are almost always used.

It is evident that the speed of transmission of messages must depend to a great extent on the number of currents required to form the different letters. In the Morse system about three currents are

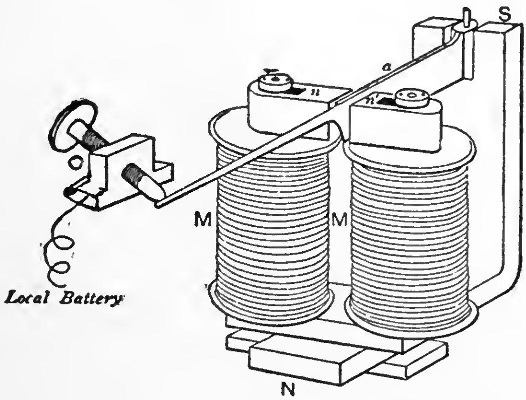

FIG. 38.—Polarized Relay. S N, permanent steel magnet whose North-seeking pole is bifurcated, its branches making the core of the electro-magnet M M, and terminating in the pieces *n* and *n'*, between which works the soft-iron armature or tongue *a*; connection is made with the local battery by means of the contact-piece C whenever a current passes through the coils M M.

wanted on an average for each letter. Inventors have therefore endeavored to construct apparatus in which fewer should be necessary. The most successful of these is Hughes' printing telegraph, which requires only one current for each letter, and which can also print its messages (transmitted in a third of the time occupied by a Morse instrument) in Roman characters. The apparatus is, however, so complicated that it can only be entrusted to a thoroughly trained and skilled operator; its use is therefore confined to very important telegraphic lines.

The Morse sounder (for which the Morse key is used as a commutator) is a non-recording instrument, and its signals appeal to the ear instead of to the eye. Its simplest form is one in which a small electro-magnet is supplied with an armature in the form of a lever, the free end of which works between two stops, and taps against one when the current starts, and against the other when it ceases. The intervals between the taps are made longer or shorter according to whether a dash or a dot is to be represented, a short pause corresponding to a dot and a longer one to a dash. It is evident that in this system mistakes are more liable to be made in a message than where reference can be had to recorded signs. Nevertheless, with skilled operators errors very rarely occur, and the greater rapidity with which transcription can take place offers an advantage which in America, at all events, outweighs other considerations, for the sounder is used almost to the exclusion of any other instrument. It is also widely adopted in India.

Submarine signaling, where the distance is great, requires special and very delicate instruments, the currents being too weak to work satisfactorily with any ordinary apparatus.[1] For a considerable time Sir William Thomson's mirror galvanometer (described in Chapter iii, of Part III, p. 87) was almost exclusively used, but owing to the great fatigue to the eyes incurred by watching the movements of the little spot of light for a long time together, this instrument has now been to a great extent superseded for signaling purposes by another invention from the same high quarter, the syphon recorder, which by means of a flat coil of wire in circuit with the line, and suspended between two powerful electro-magnets, communicates motions to a very fine glass syphon, dipping into an insulated metal ink vessel, and having its other end adjusted over a paper strip. When a message is to be recorded, the vessel of ink is connected with a charged conductor, and the result is to force the drops of ink on to the paper, unrolled by clockwork, as in the Morse instruments. The mechanism is so arranged that when a current is passing, the point of the syphon moves alternately to one side and the other of the centre of the paper, and thus two lines of ink spots are made, one of which corresponds to the dots and the other to the dashes of the Morse code.

It is hardly necessary to describe the mode in which ordinary overland telegraph wires are conveyed from place to place. We are but too familiar with the gaunt wooden posts, and the wire lines suspended from them, which make our railroads even more hideous than they would otherwise be. The wires thus employed are made of galvanized iron (iron coated with zinc), and every post carries insulating supports through which the wires pass. In England, and Europe generally, overhead wires are replaced in large towns by an underground system, in which a number of wires are enclosed in iron or earthenware pipes and buried in the soil. These wires are made of copper, and each one is insulated by a gutta-percha covering. But for the greater cost and small mechanical strength of copper wires, they would always be preferable to iron for telegraphic purposes, owing to their much lower specific resistance and their greater power of withstanding exposure to the weather. If the wires break, come into contact with other wires, or with conductors connected to the

[1] The current given out by the Atlantic cable, when twenty-five words per minute are being transmitted, is one-millionth of an ampère.

earth, there ensue total or partial interruptions of the currents they convey, technically known as "faults." Various means are taken to prevent these and to ensure their speedy remedy when they do occur. The most important precautions are the thorough insulation of the wires, the frequent introduction of "testing-boxes" along the circuit, which enable the real position of the fault to be speedily discovered, and (in the case of overhead wires) the metallic connection of each one of the insulating supports with the earth. This obviates the danger of one wire leaking into another (which might otherwise frequently occur in wet weather), by supplying an easier and more direct path to the earth for the leaking current. These earth connections of the insulators also serve the important purpose of lightning conductors, which are indispensable both along the line and at the signal stations, as without them the lightning discharge might travel along the wires, not only interrupting the messages, but destroying the telegraphic instruments, and injuring or even killing the operators. Such accidents have more than once happened. In wires carried underground another difficulty has to be contended against, viz., the taking up by the wires of a static charge of opposite sign to that of the surrounding earth, which, in fact, acts as one coating, while the wires act as the other, of a Leyden jar. This condition of things weakens the current and prevents rapid signaling; but it is not often that underground wires are of sufficient length for the currents they convey to suffer seriously from this cause. It is far otherwise with the submarine cables, some of which (as those which cross the Atlantic) are 2,000 miles or more long. Special means have then to be taken to obviate the delay, and even failure, of transmission. The most effectual seems to be employing alternate positive and negative currents, as then each one as it passes through the cable counteracts the effect of its predecessor. The use of the exceedingly delicate recording instruments already referred to, is another important consideration, as a much weaker current is then able to suffice.

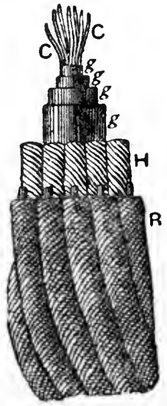

FIG. 39.—Section of an Atlantic cable. R, outer casing of tanned hemp ropes enclosing stout iron wires; H, inner casing of tanned hemp ropes surrounding the four gutta-percha layers *g g*: C C, strand of copper wire (untwisted) forming the conductor by means of which the messages are transmitted.

Submarine cables, especially when of great length, require to be exceedingly strong, in order to withstand the enormous pressure of water they encounter when being lowered, the buffeting of the waves near shore, and the friction against the uneven and often rocky bed of the ocean. The Atlantic cables, of which there are now nine, are made of seven strands of copper wire, covered with four layers of gutta-percha encased in tanned hemp. Over this are twisted stout iron wires, also covered with hemp. Fig. 39 gives a representation of a portion of an Atlantic cable, showing the different layers.

One of the most important improvements in modern telegraphy is the introduction of the duplex system, which enables two messages to be sent in opposite directions along the same wire at the same time. In order to do this, it is necessary that when a signal is transmitted from one station to another, the receiving instrument at the sending station should not be affected, but remain free to indicate any message traveling to it from the opposite direction. This end is attained in various ways; and not only has duplex telegraphy come into constant use, but still further developments have taken place, so that a single wire is now able to convey four or more messages at the same time. Quadruplex telegraphy, however, entails the necessity for two sending and two receiving instruments at each station.

Currents of low electro-motive force are the most suitable in telegraphy, as they are then less liable to leak, and the mechanical work required of them is very slight. They are consequently almost exclusively generated by galvanic batteries. A form of Daniell's cell has been chiefly adopted in England, but the Leclanché is also excellent for telegraphic purposes and is coming widely into use.

This slight and inadequate sketch can give but a faint idea of the enormous proportions to which the science of telegraphy, for it is a science in itself, has now attained, but indeed no assertion of the fact is necessary, for we are brought face to face with it every day and almost every hour of our lives. Those multitudinous wires spreading over our continents and spanning our widest oceans may well strike us with a feeling somewhat akin to awe, for they are the nerves of the world, connecting its centres of intellectual, political and commercial activity with the remotest individual life, and flashing interchanges of thought between nation and nation.

CHAPTER V.

THE TELEPHONE.

Novelty of the idea of transmitting spoken words—Reis's telephone—Graham Bell's telephone—Weakening of the sound in transmission—Invention of the microphone—Its principle—Combination with the telephone—Transmitting and receiving instruments used in England—Feebleness of telephone currents—The Telephone Exchange system—Transmission of concerted music—Telephone wires—Necessity of guarding against induction—Means employed—Effect of earth currents and atmospheric electrical disturbances—Sensitiveness of telephone made useful as a test for weak currents—The microphone employed for medical purposes—The phonograph.

As we have seen in the preceding chapter, the possibility of communicating at a distance by means of magnetic signs, though it had never been successfully attempted when the electric telegraph was invented, was no new idea. The transmission of spoken words, however, had not even been thought of, and its accomplishment came with almost as much surprise on scientific men as on the general public; but during the last twenty-five years we have become so used to talking with persons many miles away from us, that the thing has almost ceased to excite wonder, and in many of our large towns telephonic communication is becoming as important and common as that by telegraph.

The first telephone was invented by a German, Reis, in 1860. It could not, however, transmit articulate speech, but only musical notes, whose vibrations are so much less complicated than those of the human voice in speaking that they are far more easily reproduced.[1] One of the earliest forms of Reis's telephone consisted of a conical tube of wood, across the narrow opening of which was stretched an exceedingly fine membrane. One end of a narrow strip of platinum foil rested on the centre of this membrane, while the other was attached to a binding screw. A second strip of platinum attached to another binding screw, and having a small pointed projection for making contact, was so adjusted that one end just touched that portion of the first platinum strip which rested on the membrane. The binding screws were connected to a battery, and to a wire through which the sounds were to be transmitted. When a musical note was sounded close to the membrane, the latter was set in oscillation, and at each complete vibration (*i. e.*, movement *to and fro*) made and broke circuit once, by means of the motion imparted to the platinum

[1] The possibility of reproducing sounds at a distance depends on the fact that each one is caused by certain definite and periodic vibrations. If these can be transmitted in their entirety to another place, the sound must naturally be reproduced at that place.

strips. This interrupted current was transmitted through the line wire to the receiving instrument, which consisted of a violin, on whose bridge was fastened an upright knitting needle, enclosed in a coil of fine silk-covered copper wire. The alternate magnetization and demagnetization of the knitting needle as the current flowed or ceased in the coil, produced the sound which always occurs when iron is thus treated; but since the number of times the needle was magnetized and demagnetized exactly corresponded to the number of vibrations communicated by the musical note to the membrane whose motions started and interrupted the current, those vibrations were again exactly reproduced in the motion transmitted by the needle to the air, and the note was sounded once more. Reis afterwards made many improvements in his telephone, but he never succeeded in getting it to speak. In the first place, no instrument depending entirely on interrupted currents would be delicate enough for this purpose;[1] and in the second, though he constructed very elaborate mouthpieces for his transmitters, he paid but little attention to those of his receivers, though it seems obvious enough now that they were by far the most important, being directly concerned in the reproduction of the sounds.

The first speaking telephone was invented by Professor Graham Bell, a naturalized American citizen, about four years after the appearance of Reis's telephone. It consisted of two exactly similar instruments, one used as a transmitter and the other as a receiver, and its principle is easily understood by reference to Fig. 40. A steel magnet M is terminated at the end near the mouthpiece P by a piece of soft iron surrounded by a coil of very fine copper wire, covered with silk, and having its terminals permanently connected to the binding screws S S, one of which is connected to the line wire and the other to earth. Over the coil is a thin disc of soft iron, D, tightly fastened at the edges, but with its centre free and nearly touching the end of the magnet. Above the disc is the mouthpiece, P, spoken into in the case of the transmitter, and held to the ear in the case of the receiver. When the transmitter is used, the pressure of air against the thin iron diaphragm is altered with every inflection of the speaker's voice, and it is consequently set in vibration, making (to the eye) imperceptible movements backward

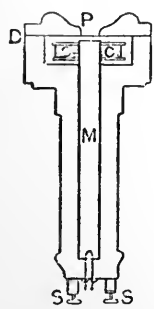

Fig. 40.—Section of Graham Bell's Telephone.

[1] The experiments of Graham Bell, whose telephone is described in the text, led him to distinguish between three kinds of currents: *intermittent* (when the current is periodically interrupted), *pulsating* (when its strength rises and falls suddenly), *undulating* (when its strength rises and falls gradually); and it is these last which are principally concerned in the transmission of human speech.

and forward in front of the wire coil, and thus starting alternate currents in it which are transmitted through the line wire to the coil of the receiving instrument, strengthening or weakening the magnetism of its core according to their direction. The result of this is to cause the second diaphragm to be attracted more or less strongly with every changing current, and so to vibrate in exactly the same manner as the diaphragm of the transmitter, imparting a similar motion to the air, and thus reproducing the sounds which originally started the currents. In fact, there is here a transformation of energy, precisely analogous to that which takes place between a dynamo and an electromotor; only instead of mechanical motion being changed into electric currents by the dynamo and back again by the motor, we have sonorous vibrations transformed into electric currents in the telephonic transmitter, and restored to their original form in the receiver. The analogy can be pursued further. Just as the same amount of work is not given out by the electro-motor that was expended on the dynamo,

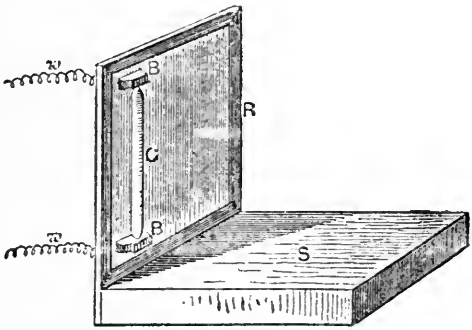

FIG. 41.—Microphone. C, carbon pencil; B B, carbon blocks with slight depressions (not represented), on which the ends of the pencil loosely rest; R, resonant board; S, wooden slab; *w w*, connection to battery.

so with the telephone also loss occurs in the process of transmission and the voice given out by Graham Bell's original apparatus was much weaker than that which it had spoken in the first instance. For this reason the instrument was not altogether satisfactory, though it could and did transmit perfectly intelligible messages over a considerable distance.

What was wanted in order to enable the telephone to attain the great practical importance which it has now reached, was the discovery of some means by which the weakening of the sounds transmitted could be obviated. Hughes, whose printing telegraph was mentioned in the preceding chapter, accomplished this by his invention of the microphone, some form of which is now invariably used as transmitter in telephonic circuits. The action of the microphone depends on the principle, that if the pressure between conductors in contact is altered, there is an alteration in the electrical resistance of the circuit of which they form a part; so that if the pressure is lessened the resistance is increased and the current becomes weaker, while increase of pressure entails diminution of resistance and the current becomes stronger. Carbon is the substance best adapted to contacts of varying resistance, and carbon is consequently used in nearly all microphones, of which Fig. 41 represents a simple but very effective kind.

When this instrument is placed in circuit with a telephone and used as a transmitter, the sounds emitted by the former are often very much louder than the original ones, simply because the varying pressure between the carbon pencil and its supports so affects the currents as greatly to strengthen the vibrations to which they give rise in the receiving diaphragm. In fact, not only are audible sounds made louder, but sounds quite inaudible to the unaided ear are rendered perfectly distinct; the walk of a fly even, over the sound-board of the microphone, being clearly distinguished in the telephonic receiver, and words spoken at some yards distance from the former being distinctly heard in the latter.

The instruments most used in England are the "Blake" transmitter, a form of microphone, and the "Bell" receiver, which is simply a Graham Bell telephone as described above. Beside a battery and the transmitting and receiving instruments, it is found advisable to include an induction coil in the circuit, the battery and primary coil being in connection with the transmitter, and the secondary coil with the receiver.[1]

Telephonic currents are calculated to be millions of times weaker than those used in ordinary telegraphy, and their alternations are so excessively rapid that there is no instrument delicate enough to make their presence known by optical signs. Their ready detection by the ear is consequently a striking proof of its extreme sensitiveness to any periodic movement, however slight.

The Telephone Exchange system, owing to which telephonic communication in our large towns has reached its present state of perfection, must not be passed over in silence. In principle it much resembles an electric-lighting installation. Just as the latter has its central and sub-stations, so the Telephone Exchange has its central and local exchanges connected by means of "trunk" wires. Each local exchange is connected to one or more others, and every subscriber has a private wire by means of which he can communicate with the local exchange to which he is attached. He is provided in his own house or office with a telephonic apparatus, consisting of a transmitter, a receiver, a battery, and a small magneto machine for making call signals, and a number by which he is to be known at the

[1] In the original Graham Bell telephone no battery was needed, the currents being generated in the transmitter by the movements of the diaphragm in front of the magnet; but where a microphone is used a separate generator is required.

exchange is assigned to him. When he wishes to speak with another subscriber, he signals to his own local exchange, and if the second subscriber belongs to it also they are put in immediate communication by having their respective telephonic circuits connected to each other. If the second subscriber belongs to a different local exchange, the signal is sent on to that, and communication is then opened between the persons who wish to converse by means of the two exchanges. If, however, the subscribers belong to local exchanges, which are not connected with each other, the Central Exchange, with which all are connected, is signaled, and communication is set up through that. The institutor of this exceedingly practical and well devised system was the father-in-law of Professor Graham Bell, Mr. Hubbard, who seems to have seen from the first the great possibilities of his son-in-law's invention.

The telephone is now often used for the transmission of music as well as of speech, whole concerts being made audible at distant places. Special arrangements are, of course, necessary in this case, as many considerations have to be attended to. It is necessary that the instrumental and vocal performances should preserve their due proportion of sound with regard to each other; that all extraneous sounds, such as persons walking about the stage of the concert-room, etc., should be excluded; and that the position of the singers should not interfere with the effect produced. All these difficulties have been successfully surmounted, even that of sufficiently insulating the transmitting microphones from any sounds but the music. To effect this they are placed on thick layers of lead covered with gutta-percha.[1]

It is most common to employ overhead wires for telephonic purposes, but in some places (as in Paris) underground cables are used. In any case, it is most important if the telephone wires are near others employed for different electrical work—such as telegraphy—to guard against the effects of induction, as the extreme sensitiveness of the telephone renders it specially liable to be interfered with by them,[2] and to have its true message interrupted or spoiled by sounds which have nothing whatever to do with it. A return wire (instead of the

[1] It is exceedingly difficult to insulate sound, and no substance so perfect for this purpose as gutta-percha is for insulating electricity has yet been discovered. Professor Hughes, the inventor of the microphone, says, "The question of insulation has now become one of necessity, as the microphone has opened to us a world of sounds, of the existence of which we were unaware. If we can insulate the instrument so as to direct its powers on any single object, as on a moving fly, it will be possible to investigate that object undisturbed by the pandemonium of sounds which at present the microphone reveals where we thought complete silence prevailed."—Quoted from "Electricity in the Service of Man," p. 723.

[2] It is, indeed, through using the telephone as a testing instrument that the fact before suspected has been proved, that any wire near another wire conveying an electric current has an induced current given rise to in it, however short the wires may be.

earth circuit) is generally found an efficient protection; but other means are also used for underground wires, one of which is to sheathe the telephone wire in an iron covering, so that induction shall take place in this and leave the wire itself unaffected.[1] "Earth currents" often produce disturbances in the telephone, causing a peculiar crackling noise, and thunderstorms give rise to very powerful effects. A flash of lightning too distant to be seen may produce a sound in the telephone, and it is stated that this often occurs before the flash, showing that inductive action must have taken place previous to the discharge.

The extreme sensitiveness of the telephone renders it very useful as a testing instrument for weak currents, there being apparently none so feeble that it will not give evidence of their presence; and a special apparatus devised by Professor Hughes, and called the *induction balance*, has been made of great use for the instantaneous testing of metals. It consists of a battery connected to two small primary coils, near each of which is a secondary coil in circuit with a telephone. The arrangements are so made that the currents in the secondary coils are opposite, and exactly equal in strength. Now, two equal and opposite currents destroy each other; so while this condition of things obtains, there is no sound in the telephone; but if one or the other current is ever so slightly increased or diminished in strength, the equilibrium of the balance is disturbed and an electro-motive force arises sufficient to cause a sound in the telephone. The testing of metals is thus carried out. Within each secondary coil is a box containing the specimens to be tested. If they are exactly similar, as for instance two genuine sovereigns would be, no sound is heard in the telephone; but if a difference exists, such as that between a true and false coin, the currents in the secondary coils no longer balance each other, and the telephone emits its warning note.

The microphone has been made very serviceable for medical purposes, and special instruments, such as the "miophone" and the "sphygmophone," have been constructed for the examination of the muscles, pulse, veins, arteries, etc., in the human body; and there is no doubt that in time the use of such apparatus will become widely extended.

During the last two years public attention has been much drawn to an invention as surprising and ingenious as that of the telephone, viz., the *phonograph;* and though this instrument is not electrical, it can hardly be passed over in silence, for it was devised and perfected by the great American inventor, to whom we owe so many marvels of applied electrical science; and, moreover, in its latest form the

[1] It is equally necessary to guard telephone wires from induction by each other, or else messages sent by one travel along the others also, and the words are reproduced at several receivers.

phonograph is driven by small electro-motors, deriving the necessary current from a battery of one or two cells. Electricity has therefore been utilized for it; and, moreover, it is stated that Edison is endeavoring to combine the phonograph with the telephone in such a way that even if no listener is at hand the latter can record its message to be heard when convenient. The work of the phonograph is to store spoken words or any desired sound, and to reproduce them when required. In order to effect this, it is necessary that the sonorous vibrations should make a permanent impression on some suitable substance, and that this impression should be able to give rise to exactly similar vibrations to those which produced it.

Edison's first phonograph consisted of a brass cylinder, turned by a handle, and on which was cut a spiral groove. A piece of tinfoil was wrapped round the cylinder, and over it was fastened a metal diaphragm, having a metal point attached which rested on the tinfoil. Above the diaphragm was a mouthpiece. When the latter was spoken into, the diaphragm was caused to vibrate, and the cylinder being set in revolution at the same time the metal point made a series of indentations, the depth of each varying with the strength of the vibration causing it; and this, of course, with the various inflections of the voice. These indentations were the record of the spoken words, and when the latter had to be reproduced a mouthpiece was held over a diaphragm exactly similar to the first, but placed with its attached point on the opposite side of the cylinder, which was revolved as nearly as possible at the same rate as when the record was being made. The second diaphragm was thus thrown into vibration exactly corresponding to that of the first, and the spoken words were reproduced. The sound was, however, thin and metallic; the record on the tinfoil wore out after being used a few times; and the instrument would only give satisfactory results in the hands of an expert, and not always then. Though interesting and ingenious, it was therefore only a scientific toy. In Edison's perfected phonograph, first exhibited in England in 1888, the brass cylinder of the original instrument is replaced by one of solid wax, and the metal point by a cutting style; so that, instead of a series of indentations, a wavy line is made in the spiral groove. The metallic twang and unevenness of speech is thus done away with, and the true timbre and all the inflections of the voice are reproduced; moreover, the record on wax is far more durable than that on the tinfoil, for one of these waxen cylinders may be used more than a thousand times, and yet show no sign of deterioration. Impressions can be taken of them to any number desired, so that without speaking the record more than once it can be indefinitely multiplied; and since the mechanism for revolving the cylinders, etc., is exactly the same in every instrument, they can be sent about by post to any person who possesses a phonograph, and be made to reproduce their recorded speech or music for his benefit. Usually it is necessary to insert acoustic tubes in the ears in order to hear the phonograph, but the necessity for this can be obviated by placing a suitable funnel on the instrument, and its sounds are then made audible to a roomful of people at once. Distinctness is, however, lost by this process. The only obstacle which seems to lie in the way of the adoption of the phonograph for everyday purposes, is the fact that the cylinders require careful adjustment when put into the instrument, and therefore a certain amount of skill is necessary. It is hardly probable, however, that so slight a reason will long keep the use of the phonograph in abeyance. The graphophone, which, though improved from Edison's original phonograph, was not perfected by himself, requires less skill in the adjustment of the cylinders. On the other hand, its intonation is not so perfect.

CHAPTER VI.

ELECTRO-METALLURGY AND MISCELLANEOUS APPLIANCES OF ELECTRICITY.

Electro-plating—Dynamos used to generate the necessary currents—Quantity of current the important consideration—The "bath"—Anode must be made of the same metal which is to be deposited—Electrotyping – Method of obtaining fac-similes of medals—Of wood-engravings – Reduction of metals from their ores—Fusion of metals with high melting-points—Welding—Medical appliances of electricity—Sewer purification—Firing of submarine mines—Electric bells—Alarms—Clocks—Conjectured possibility of transmitting vision.

IT has already been stated that an electric current is able to separate metals from their solutions, and that the liberated metallic atoms are always deposited at the negative electrode, or kathode. This property of the electric current has been made of great practical use in the now familiar process of electro-plating, under which comprehensive term is usually included the covering of any metal with the coating of another, whether the latter be precious or not.

Formerly batteries were used to generate the required currents, but it is now found better and more convenient to employ continuous-current dynamos for this purpose. They are, however, of a different kind from those used for electric lighting and transmission of power, in both of which a current of high electro-motive force is required. This is not necessary in the case of the deposition of metals. Quantity of current is there the important consideration, and the dynamos are constructed accordingly. The method employed is as follows:

The object to be plated is made the negative electrode, and immersed in an electrolytic cell, known for this purpose as a "*bath*," and filled with an acid solution containing a salt of the metal, say silver, to be deposited. The positive electrode is made in this case of a plate of pure silver, and immersed in the same solution. The current is then passed through the bath, the electrolytic liquid is decomposed, oxygen is liberated at the anode, and silver deposited on the kathode, *i. e.*, on the object to be plated, and the process is continued until a coating of silver of sufficient thickness is obtained. If the plaiting is to be of gold or copper, exactly the same method is followed, only the solution is different, and in each case must contain a salt of the metal to be deposited. The object of making the anode of the same metal is, that by its gradually dissolving in the acid it may replace that which is being deposited on the kathode. Otherwise all the metal in the solution would be used up, and the process come to an end before the requisite thickness of coating had been obtained.

Electrotyping is another most important branch of electro-metallurgy. In this industry electrolytic deposition is used to obtain fac-similes of medals, wood-engravings, ordinary printing type, and even daguerreotypes. To obtain the fac-simile of a medal, a cast of the latter is first taken in some suitable substance, which if non-conducting is rubbed over with metallic powder to make it conduct. It is then immersed in a "bath" containing a solution of copper, and forms the negative electrode. The positive electrode consists of a solid bar or plate of copper. The current is then started and continued till a thick coating of copper is deposited on the mold, from which it can afterwards be easily detached. For fac-similes of wood engraving, a mold of gutta-percha is first taken from the block itself, and then subjected to electrolytic deposition of copper for twenty-four hours. The engraving is then found to be reproduced on a very thin plate of copper, which is strengthened by having melted type-metal run in at the back. From the "electrotype" many thousand impressions can be taken, and it is chiefly owing to the facility and accuracy of the process, combined with its comparative inexpensiveness, that the number of illustrated books has so greatly increased of late years. When all impressions had to be taken from the block itself but few good ones could be obtained, as the wood-engraving rapidly wore out.

The intense heat of the electric arc causes it to be extensively used in the reduction of metals from their ores. Even the most refractory yield to this treatment, but the current required in order to produce the necessary amount of heat, often attains several thousand ampères, the electro-motive force being, however, quite low. Currents of the same kind are also used for the fusion of metals with high melting-points, and for welding, complete success having been attained even with aluminum, though all other means proved inadequate. For welding, however, it is not the electric arc which is used, but what may be called an "incandescent" method. The ends of the two pieces of metal to be welded are pressed together and the current passed through them, when the resistance it encounters at the point of contact causes the development of a heat sufficient to soften the metals, so as to allow of their being easily united.

The best known and most important practical appliances of electricity have now been touched on, but there are many minor uses (some of which should perhaps hardly be called minor) which deserve, at least, mention.

In the first place, attempts are increasingly made, and with increasing success, to use electric currents as curative agents,[1] and there can be little doubt that, as the natural electrical condition of the human body becomes better understood, they will prove of the utmost importance for medical purposes. Paralysis and kindred diseases are very frequently treated by electricity now; but no such course should ever be pursued except by the advice and under the direction of a properly qualified medical practitioner who has made a study of the subject. Amateur attempts, when not positively dangerous, are far more likely to result in harm than good to the patient for whose benefit they are intended. Besides paralysis, certain kinds of tumor and aneurism have been cured by means of electricity. For this purpose electrolysis is employed; it sets up chemical processes in the affected parts which result in the dispersion of the tumor or the hardening of the aneurism.

There is a hope that by means of a recent invention electrolysis may be utilized for a yet more important purpose than the cure of disease, viz., its prevention on a large scale, through ridding sewers of their poisonous gases, and thus rendering them innocuous. Electric currents have been also experimentally applied with some success to agriculture.

From these beneficial uses, it seems sad to turn to the destructive purposes which electricity is made to serve in warfare. It is now almost the sole agent employed for firing submarine mines and torpedoes, and many most ingenious contrivances have been devised, enabling an operator on shore to explode a mine some distance out at sea, at the very moment an enemy's vessel is passing over it.

Besides lighting, electricity is made to serve various domestic purposes. Electric bells are now so common and so evidently superior to all other kinds that they will soon have no rivals left. Electric alarms are also frequently used in large establishments, and in some cases electrically-controlled clocks. There seems, indeed, no end to the ways in which man may employ this marvelous and ubiquitous

[1] Induction currents are most frequently employed.

agent, so mighty in its resources and yet so easily controlled. It has even been hoped that by its means, vision, as well as speech, might be reproduced at a distance, and in fact some partially successful experiments in this direction were made more than ten years ago by Professors Ayrton and Perry. The problems to solve are so many and so intricate, however, and the constructive difficulties to be overcome so great, that it hardly seems possible an invention should ever be made which would be to the eye what the telephone is to the ear. Nevertheless, the marvelous adaptations of applied electrical science have astonished us so often that it may well be another surprise is in store for us here.

CONCLUDING CHAPTER.

"WHAT IS ELECTRICITY?"

Impossibility of giving a categorical answer to the question—Analogy with the case of gravity—Our knowledge of electricity in reality greater—Possible connection between the two sets of phenomena—Important results achieved by electrical science—Connection between electricity and light—Electro-magnetic disturbances propagated through space with the velocity of light—Space not empty—The ether—Meaning of radiation—Of "radiant" heat, light, and electricity—Electro-magnetic theory of light—Undulatory theory of light—Experimental proofs on which it rests—Necessity for similar proof in the case of electro-magnetic undulations—Hertz's experiments—Their conclusive result and consequent immense importance to physical science—Concluding remarks.

TO the question, "What is Electricity?" it is impossible as yet to give any certain answer—as impossible as to say what the force of gravity is; for, though the fact is perhaps not generally realized, we know as little of the nature of the one agent as the other. We say that "electricity," or electrified bodies, "attract;" we say that gravity is a force of attraction; but neither of these assertions is an explanation, it is simply a statement of facts. In reality more is known about electricity than about gravity, for it is ascertained to some extent in what way the electrical forces are propagated, whereas with respect to gravity we are absolutely ignorant as to its manner of working. We simply know that its observed effects are governed by unalterable laws, and it may perhaps be said that the only hope of discovering anything further respecting its action lies in the direction of there being found a connection between the phenomena of gravity and those of electricity, a possibility which gives a yet additional interest both to the experimental and theoretical study of the latter. Already a great part of the domain of physics, and nearly all that of chemistry, has been revolutionized by the growth of electrical science, and if somewhat extravagant expectations are entertained about its future possibilities, they seem justified by the achievements it has already made.

In the present work but little has been formally said respecting any theory as to the nature of electricity, but it has been intimated that the electrical forces are propagated through the ether, and that there is a very close connection between electricity and light. To the observations already made it may be added that certain substances, notably selenium, have their electrical resistance very considerably altered if exposed to the action of light, also that a polarized ray of light in a strong magnetic field has its angle of polarization twisted into a different position.[1] But by far the most important point of connection between these two mysterious agents, light and electricity, is that the velocity with which an electro-magnetic disturbance is propagated through space is equal to the velocity of light, being in round numbers 186,000 miles a second.[2] Traveling at this rate, light takes eight minutes to reach the earth from the sun, and the fact of its thus requiring time to travel is sufficient to show us that space is not, as it is so often supposed to be, empty, but that there is something present in it which transmits light, and, we may add, transmits also heat and electricity. The structure of this something, which it has been agreed to call "ether," is now, and perhaps always will be, unknown, but it is understood that it must be totally different to that of any other form of matter with which we are acquainted, though it appears to possess what may be called the counterparts of ordinary material qualities, such as elasticity and density. Heat, light, and electrical energy are propagated through this medium in a way known as *radiation*, *i. e.*, in spherical waves. The term "radiant heat" is becoming familiar even to the non-scientific, but it must not be supposed that it designates any particular kind of heat. It simply means heat traveling in a particular kind of way, during which it does not appear as heat at all, but as motion; and the same is true of light and of "radiant" electricity. There is no light, as we understand light, except where the presence of gross matter modifies the action of the ether; the interplanetary and interstellar spaces are dark. Neither is there any sensible manifestation of heat or of electrical energy. But there is motion; and this motion is capable, under the right circumstances, of appearing either as light or heat or electrical energy.

If, however, light and electrical undulations are propagated through

[1] See note at the conclusion of the chapter, p. 147.

[2] By an electro-magnetic disturbance is meant such a disturbance as is given rise to, for instance, by the discharge of a Leyden jar, or the make and break of a galvanic circuit.

the same medium, with the same velocity, in the same manner, it is not difficult to conceive that they must be more than merely related; they must be to a great extent identical. This has been recognized by advanced scientific thinkers since the time—now more than twenty-five years ago—when the great English physicist and mathematician, Clerk Maxwell, published his "Electro-Magnetic Theory of Light," of which the first experimental proof was given in 1877 by Professors Ayrton and Perry, who found that the ratio of the electro-magnetic to the electro-static unit of electric quantity[1] was equal to the velocity of light, as Clerk Maxwell had shown that it must be, if light were propagated as an electro-magnetic disturbance. In 1888 another great step was made, for the existence of electro-magnetic waves, in all respects similar to those of light, was detected by direct experiment, and that date consequently marks a memorable era in the history of modern science. In order that the reader may be enabled to comprehend the nature of these now celebrated experiments, first carried out by a young German physicist named Hertz, and since him by others, reference must be made to what is known as the "undulatory theory" of light, and to the proofs on which it rests.

For a very considerable time it has been understood that light is caused by motion of some kind. The question was whether that motion was one of material particles shot out from the luminous body, as Newton supposed, or whether it was a vibratory movement started by the luminous body in the ether, through which it was propagated. The latter theory was always found by far the most capable of explaining luminous phenomena, and experimental proof of it was finally given by two eminent scientific men, Young and Fresnel, the one English and the other French, independently. Connected with any wave movement, there is a phenomenon called interference, which is caused by the action of waves on each other, and which can be roughly observed by any one watching water-waves turned back from a sea-wall upon those still advancing. It will be noticed that the direct and reflected waves meet each other in one of two ways, either crest joins crest and furrow furrow, with the result of making a much larger wave, or crest joins furrow and furrow crest, and there is a patch of comparatively calm water. A much better way of observing the effects of interference is to suspend a cord to the ceiling of a room, and taking the free end in the hand impart to it a series of periodical impulses. Waves are thus given rise to in the cord which run up to the ceiling, are there reflected, and return to the hand of the operator; and while this is going on, if the rate of motion of the hand be right for the length and mass of the cord, the latter will divide itself into a regular succession of loops, the centre of each one of which is a point of greatest amplitude of vibration, *i. e.*, where the swing of the cord

[1] Generally known as "v."

particles from side to side is widest, while between each loop is a point of no vibration, technically called a node. Where the loops occur, the direct and reflected waves meet each other in what is called the same phase of vibration (supposing they were water-waves, both would be rising and both falling at the same time); where the nodes occur, they meet in opposite phases of vibration (in water-waves one would be rising and one falling), so that the same point being acted on by two equal and contrary forces remains at rest.

Now, if light travels in waves, wherever direct and reflected waves of light meet each other there must be a similar phenomenon to that exhibited in the cord, and it can be observed by causing two pencils of red, or of any monochromous light to pass through two small apertures into a darkened room, and fall upon a white screen in such a way that certain portions of it are illuminated by reflected rays from both pencils, care being taken, as regards each pencil, that only light of one phase should reach the illuminated parts of the screen. There then appear on the latter alternate bands of the colored light and of darkness, which correspond exactly to the loops and nodes in the cord, the colored bands being caused by those light waves which meet in the same phase of vibration, and the dark by those which meet in opposite phases. That this is really the case can be proved by shutting off the light from one of the pencils, when the dark bands disappear, thus showing that they were caused by interference. This experiment places beyond a doubt the truth of the undulatory theory of light; and in order to prove the electro-magnetic theory of light, or, in other words, the existence of electro-magnetic undulations identical with those of light, an experiment of the same kind, but of an electrical nature, was necessary.

The difficulty lay in the extraordinary rapidity of vibration which it was necessary to attain, in order to procure waves manageable within the walls of a laboratory. The ordinary oscillations of a Leyden jar discharge, which are at the rate of one million a second, were far too slow, for the ether wave length corresponding to this period (viz., the millionth of a second) is 300 metres, and one of a few feet only was required. To obtain this it was necessary to produce vibrations of the order of 100 million per second, and even when this difficulty had been surmounted, by the construction of a special apparatus whose capacity, resistance and self-induction were so proportioned as to give vibrations of the required rapidity, there remained the question, How could they be observed? They could not be seen. Ether-waves which can be seen are waves of light, and their rate of vibration is several billion times a second. They could not be heard. To render them audible they must be made very much slower, as was done by Dr. Oliver Lodge in the experiment described in Chapter IV. of Part III. In order to observe electrical waves too long to be seen, and too short to be heard, Hertz made use of the principle of resonance, the most familiar example of which is that of a tuning-fork, which when sounded is able to make any neighboring tuning-fork of the same pitch as itself sound also, simply because their periods of vibration being the same, the second tuning-fork absorbs the vibrations of the first, and gives out exactly similar ones. Hertz, therefore, constructed two electrical circuits whose periods of vibration were identical. One he called the oscillator, and the other the resonator. The latter included a small spark gap, and was placed between the oscillator and the wall. When vibrations were set up in the oscillator, induced vibrations were set up in the resonator, and in a darkened room an infinitesimal spark was seen to cross the gap. By moving the resonator about to different parts of the room, Hertz found that in some places the sparking was more active, and in some it ceased altogether, and he also found that these spots of electric activity and repose succeeded each other at regular intervals, thus showing that they were due to the interference of direct and reflected waves, and were, in fact, a phenomenon exactly similar to the nodes and loops in the cord, and the dark and light bands, described above. By further developments of his experiment, Hertz was able to prove that these electro-magnetic waves are transverse, like light waves, viz., that the vibrations take place across the line of propagation; and, moreover, that every effect which can be observed with the one kind of waves can be observed with the other. Thus, both alike can be reflected, refracted, and polarized. Nothing is, therefore, wanting for the complete establishment of the "electro-magnetic theory of light." Electrical, like luminous phenomena, are all referable to the action of the ether, and we may say either that electrical science includes the whole of optics, or that optics includes the whole of electrical science, whichever way we like to put it. This is the commencement of a very splendid generalization. It is, without doubt, one of the most important advances in physical science which has ever been made, and it is with a feeling of intense expectation that the question arises in our minds, "What will be the next?" Scientific men seem trembling on the verge of some discovery which will come nearer to the solution of the problems surrounding the ultimate nature of matter than even a few years ago was deemed possible. Will this discovery be made in our own generation, or in the next, or perhaps not for many more to come? We cannot tell. At any moment it seems possible, and yet it may be long deferred; but present knowledge would lead us to suppose that when it does come it will be as amazing in its simplicity as in the depth and wideness of its scope. Already some of our leading physicists are beginning to formulate the query—infinitely more far-reaching than that which heads this chapter—whether all existing things are not modifications of that ether but a short time since deemed hypothetical, and which is now proved to be the medium through which we receive the life-giving and life-sustaining energy emanating from the sun. Startling as such an idea may be at first sight, there is an inexpressible grandeur in the conception which it leads us to form of the unity of design pervading the whole of creation, and of that Infinite Mind which human reason—its faint reflection—is being more and more taught to realize as underlying and interpenetrating the "material universe."

NOTE ON THE POLARIZATION AND MAGNETIZATION OF LIGHT.

IT was mentioned in the preceding chapter that the vibrations of light are of the transversal kind, *i. e.*, that they take place across the line of propagation, and in a ray of ordinary light they are executed *in all directions* across this line. If, however, such a ray be caused to pass through a thin slice of tourmaline, or a Nicol's prism, it emerges with all its vibrations reduced to one plane, and is in the condition known as that of *plane polarized light*, the tourmaline, or Nicol's prism, through which it has passed being called the *polarizer*. The plane of polarization can be discovered by placing a second slice of tourmaline, or Nicol's prism, called the *analyzer*, in the path of the polarized ray, for a position can be found for the analyzer in which it is opaque to the incident polarized ray, whose light is consequently quenched altogether. This position is always at right angles to that of the polarizer, to the plane of polarization of the ray, and to the position in which the analyzer would itself polarize light.

By the "magnetization" of light, discovered and named by Faraday, the following effect is meant. If a bar of a certain kind of "heavy glass"[1] be placed across the poles of a powerful electro-magnet, and a ray of polarized light caused to pass through it and enter an analyzer on the opposite side, it is found that when the current is passing through the coils of the electro-magnet the position in which the analyzer causes darkness to occur is not the same as when there is no current. This shows that the plane of polarization of the ray has been twisted round under the magnetic influence, and proves a direct

[1] A tube containing bi-sulphide of carbon will have the same effect, which can also be produced in a minor degree by other substances, and to a very small extent by air.

action of magnetism on light. The direction in which the plane of polarization is twisted is for most dia-magnetic substances the same as that of the magnetizing current, but for many magnetic substances contrary to it. Further proof of the rotatory effect produced by magnetism on light is given by the fact that a polarized ray reflected from a magnet or an electro-magnet also has its plane of polarization twisted round. If the reflection takes place from a pole, the plane of polarization is turned in a contrary direction to that of the flow of the magnetizing current; if from a point at the side of the magnet, in the same direction, provided the planes of incidence and polarization are parallel. If they are perpendicular to each other, the direction of rotation is only the same as that of the magnetizing current if the angle of incidence exceeds 75°. For lesser angles the rotation is opposite to the direction of the current.

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Beacon Lights of Science

THE ELECTRIC LIGHT

AND

THE STORING OF

ELECTRICAL ENERGY

BY

GERALD MOLLOY, D.D., D.SC.

ILLUSTRATED

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Beacon Lights of Science

THE ELECTRIC LIGHT

TWO LECTURES

DELIVERED IN THE THEATRE OF THE ROYAL DUBLIN SOCIETY

MARCH, 1888

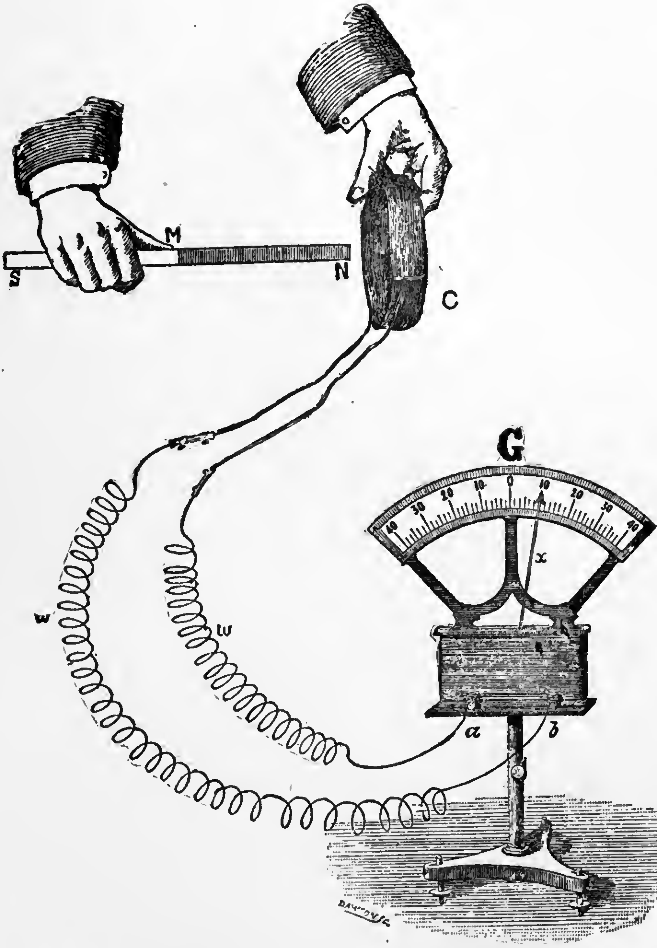
LECTURE I.

HOW THE ELECTRIC CURRENT IS PRODUCED.

AN Electric Light installation consists essentially of two parts: one part, in which an electric current is generated; and another, in which the energy of the current is converted into light. The electric current is now almost universally produced, for the purposes of Electric Lighting, by means of a Dynamo-Electric machine, or, as it is more familiarly called, a Dynamo; and the energy of the current is converted into light in some one form or other of the Electric Lamp. I propose, then, in my Lecture to-day, to give you a short account of the Dynamo, tracing the history of its development from its first origin down to its present high degree of perfection; and in my second Lecture, I will deal with the Electric Lamp, and explain, as far as I can, the process by which the electric current is made to yield us the electric light.

Faraday's Discovery.—In the month of November, 1831, Faraday read a paper before the Royal Society of London, in which he announced, for the first time, a discovery which will be memorable forever in the annals of science. He showed that when a closed circuit, that is to say, a conductor the ends of which are connected together electrically, is moved in the presence of a magnet, a current of electricity is developed in the circuit, during the time of its motion. It would detain us too long to repeat all the experiments by which this discovery was established, but I can give you a general idea of the nature of these experiments in a few words.

I have got here, in my left hand, a coil of copper wire, which is covered with an insulating material, so that a current of electricity, developed in the wire, may not pass across from spiral to spiral, but must travel all round each spiral before passing to the next. In my



CURRENT OF ELECTRICITY PRODUCED BY THE MOTION OF A COIL OF WIRE IN PRESENCE OF A MAGNET.

M Bar Magnet.
C Coil of Copper Wire.
w w Wires conveying the Current.
G Sensitive Galvanometer.
a b Binding Screws of Galvanometer.
x Index of Galvanometer.

right hand I hold an ordinary bar magnet. Now what Faraday showed was simply this: that if the ends of the copper wire are connected together, forming what is called a closed circuit, a current of electricity will be developed in the coil, when it is moved in the presence of the magnet.

To demonstrate the presence of this electric current, I have placed on the table a very delicate galvanometer, made by M. Bourbouze, of Paris. I need not tell you that a galvanometer is an instrument whose function it is to reveal the presence of a current of electricity, and at the same time to indicate the direction in which the current flows. This particular instrument before you is provided with a long index, which is visible I hope to all present, and which now points to zero on the scale: but when a current of electricity flows through the apparatus, the index will be deflected from its position of rest, and will swing to the right or to the left, according to the direction in which the current is flowing.

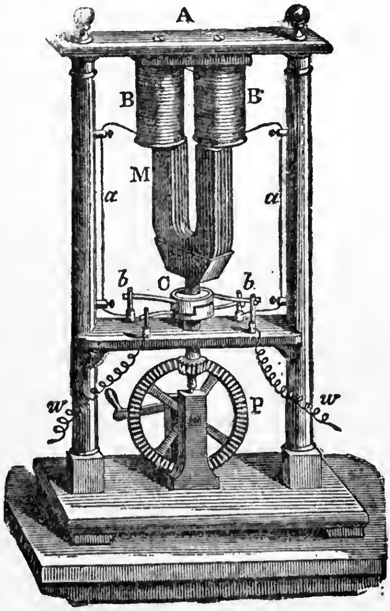
My assistant will now connect the ends of the coil with the binding screws of the galvanometer, by means of light flexible wires. In so doing, he practically makes a closed circuit, of which the coil of copper wire is one part and the galvanometer another: and now, if an electric current is developed in the coil, it must flow through the galvanometer, and its presence will be revealed by the deflection of the index.

With this apparatus I can reproduce in substance the experiments of Faraday, so as to make the results apparent to every one present. I move the coil towards the north pole of the magnet, and the index of the galvanometer swings to the right, showing that a current has passed. But observe, the index, after swinging back and forward a few times, comes to rest again, at zero; from which we may infer that, when the coil and the magnet are both at rest, no matter how close they may be, no current is produced. Next, I move the coil away from the north pole, and again the index is deflected; but this time it swings to the left, showing that the new current developed is opposite in direction to the former.

I repeat these experiments with a south pole. When I move the coil towards the south pole, the index swings to the left; when I move it away, the index swings to the right. Thus we learn that the current produced by the action of a south pole is, in each case, opposite in direction to that produced by a north pole.

Pursuing these experiments, Faraday further showed that the current is greatly intensified, if the copper wire is wound round a bar of soft iron. He also showed that the current developed is stronger, in proportion as the magnet employed is more powerful, and in proportion as the motion is more swift. And lastly, he showed that the current is equally produced, in all cases, whether the magnet is at rest and the coil is moved, as was the case in our experiments, or the coil is at rest and the magnet moved. These are the main facts which Faraday established by experiments carried out in the Royal Institution of London, just fifty-seven years ago; and upon the basis of these facts, it is simply true to say, have been built up all the Dynamo-Electric machines that are now at work in the world.

Faraday was himself fully conscious of the importance of the discovery he had made; and he believed it to be capable of many useful applications. But these applications he left to others to seek out; and having handed over his discovery to the world, with all its potency of



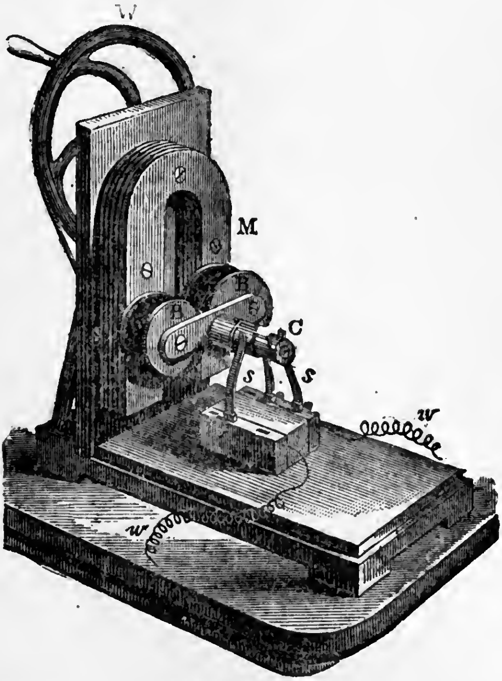
PIXII'S MACHINE, 1832.

B B Bobbins of Wire.
M Horse-shoe Magnet.
P Wheel and Pinion to drive round the Magnet.
a a Wires to carry the Currents from the Bobbins to the contact pieces *b b*.
C Commutator to collect the Currents and transmit them to the Wires *w w*.

future development, as an inheritance forever, he turned his attention to new fields of research, in the hope of discovering new truths, and enlarging still more the bounds of human knowledge.

First Machines founded on Faraday's Discovery.—The first practical application of Faraday's discovery to the construction of a machine for generating an electric current was made in 1832, by Pixii, a manufacturer of philosophical instruments in Paris. You will easily understand the construction of his machine from the diagram before you. Two bobbins of wire, B B, each having within it a core of soft iron, are mounted in a fixed position on the solid frame A. Immediately below the bobbins is a horse-shoe magnet M, so adjusted that it can be made to rotate rapidly by means of the wheel and pinion P. As the magnet rotates, its poles pass alternately close before the face of each bobbin; currents of electricity are thus generated in the bobbins, and these currents are carried, by the wires *a a*, to the spring contacts *b b*, from which they pass to the commutator C. From the commutator the currents are transmitted to the wires *w w*, by which they may be conveyed to any external circuit, for practical use.

It was soon found, however, that it was more convenient to make the bobbins of wire revolve before the poles of the magnet, than to



Clarke's Machine, 1836.

M Horse-shoe Magnet.
B B Bobbins of Wire.
W Wheel to drive the Bobbins.
C Commutator.
s s Springs to convey the Currents from the Commutator to the external Circuit, through the Wires *w w*.

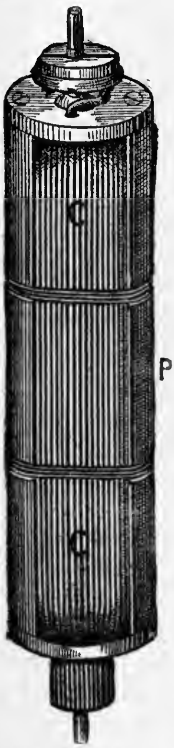
make the poles of the magnet revolve before the bobbins. This modification was first introduced by Saxton, in the year 1833, and was afterwards adopted by Clarke, whose machine, first brought out in 1836, has survived, in one form or another, down to the present day. The diagram on the wall represents one of the earliest forms of Clarke's machine: M is the horse-shoe magnet, B B are the bobbins of wire, and W is the wheel by means of which the bobbins are made to rotate before the poles of the magnet. The currents of electricity developed in the bobbins pass to the commutator C, which is fixed on the axis of rotation; and from the commutator they are conveyed by the springs *s s*, which press against the commutator as it revolves, to the wires *w w*, by which they pass into the external circuit.

Clarke's machine has been found very convenient for medical purposes, and it is in general use, even at the present day, amongst medical men, in a great variety of forms. The specimen here on the table, made by Gaiffe of Paris, is one of the most recent: it is firmly fixed in a rectangular box to make it more portable, and it is provided with a variety of appliances by which the currents developed may be conveyed to various parts of the human body.

I should tell you that, in all these machines, the electric currents developed in the coils of wire flow in one direction during one half of each revolution, and in the opposite direction during the other half revolution. You will remember that, in repeating Faraday's experiments, a little time ago, I showed you that when a coil approached a magnetic pole, the current flowed in one direction, and when the coil receded from the pole, the current flowed in the opposite direction. I showed you also that the currents developed by motion to or from a north pole are always opposite to the currents developed by motion to or from a south pole. It is a consequence of these laws that, in the machines before us, the currents generated in each half revolution of the bobbins are in opposite directions. Hence, if we connect the ends of the wire coming from the bobbins directly with an external circuit, the currents will flow alternately in opposite directions in the external circuit. But an ingenious contrivance, called a commutator, has been devised, by means of which the currents, though flowing alternately in opposite direction in the bobbins, are all sent into the external circuit in the same direction.

I need not trouble you with the mechanical details of the commutator. Enough it is to know that we have two types of machine. In one type, where the commutator is not employed, the currents in the external circuit flow alternately in opposite directions; in the other, where the commutator is introduced, the currents in the external circuit flow all in the same direction. The one type is called the alternate current machine; the other is called the continuous current machine. Both types are in general use: and both, I may say by anticipation, are at the present moment employed for producing the Electric Light.

Siemens' Armature.—In the progress of scientific discovery there are periods of activity and periods of repose. The production of Clarke's machine, in 1836, was followed by a long period of repose; for no further improvement was made from that date until 1857, when Dr. Werner Siemens, of Berlin, introduced a new method of winding the bobbin of wire, or armature, as it is called. You will have observed that, in the machines I have aready described, only one face of each bobbin comes close to the poles of the magnet; the other face is always turned away, and therefore the influence of the magnet upon it must be comparatively feeble. Siemens conceived the idea of so constructing his bobbin that each face of the coil might come close to the magnet poles, and the inductive effect of the magnet be thereby greatly increased.



SIEMENS' ARMATURE, 1857.

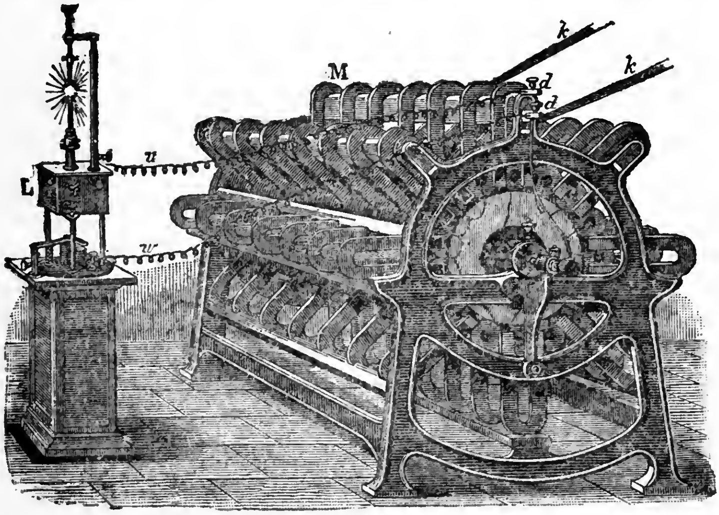
Here is one of his bobbins in the form in which they were first brought out; and here is the machine in which it works. The bobbin is prepared by taking a cylindrical bar of soft iron, and cutting a deep wide groove on both sides all along its length. The insulated copper wire is then wound, in this groove, like thread upon a shuttle. In the machine, a number of horse-shoe magnets are mounted on a stand, with all the north poles on one side, and all the south poles on the other. These poles are so shaped as to allow the cylindrical armature to fit between them, with just room enough to rotate freely.* When the armature is put in rotation each face of the coil comes alternately, first opposite one row of poles, and then opposite the other, and inductive action takes place under the most favorable conditions.

First Machines for Production of the Electric Light.—Soon after the introduction of Siemens' armature, practical men began to realize that the power of these machines might be increased almost indefinitely. It was only necessary, following out the principles laid down by Faraday, to get larger magnets and a greater number of them, to coil more wire on the armature, and to drive it at a greater speed, and an electric current might be generated far surpassing any that had ever been obtained from batteries. It was suggested, too, that such currents might be used with great advantage to produce the electric light for the illumination of Lighthouses.

This idea was taken up about the same time in England and in France, and was soon carried to a successful issue. A very powerful machine, constructed by the Alliance Company, in France, and driven by a steam-engine, was established at the Lighthouse of Cape La Hève, near Havre, about the year 1863, and used from that time forward for the production of the Electric Light. The construction of the Alliance machine may be easily understood from the diagram before you. You see here eight rows of magnets M M, mounted on a massive frame, with seven magnets in each row, or fifty-six magnets in

*For a figure of Siemens' machine, see page 21.

all. Between the poles of these magnets a large Siemens' armature is driven round by the belt *k k*; the currents are collected at the binding screws, *d d*, and are carried by the wires *w w* to the lamp L.



MACHINE OF THE ALLIANCE COMPANY, 1863.

M M Horse-shoe Permanent Magnets.
k k Belt for driving Armature.
w w Wires for conveying the Current from Machine to Lamp L.

A machine quite similar to this was constructed, in England, by Holmes, who had previously been in the service of the Alliance Company, and was mounted on the sixth of June, 1862, at the South Foreland Lighthouse, where it continued to be worked very successfully for many years. This machine, at the South Foreland, is particularly interesting, because it was set up under the direction of Faraday himself, who, at the time, was scientific adviser to the Elder Brethren of Trinity House, and who thus had the satisfaction of seeing, after the lapse of thirty years from the date of his great discovery, this offspring of his own genius already arrived at maturity, and entering on a career of usefulness which is likely to last as long as the world itself.

First Machine with Electro-magnet.—But these machines, though successful for their time, were bulky and cumbrous; and hardly had they been seen in action, when the idea was suggested that a great saving might be effected, in size and weight, by the employment of electro-magnets, instead of permanent steel magnets. An electro-magnet, as I dare say you know, consists of a bar, or plate, of very soft iron, round which is coiled an insulated copper wire. Here is one, bent into a horse-shoe shape, and suspended from this tripod stand. It shows no sensible signs of magnetic power, when I present to it a tray of iron nails. But the moment I turn on an electric current, and make it flow round the coil of copper wire, you see how the nails are suddenly attracted, and held suspended in the air, the magnetic power passing through the mass, so that they stand out in a cluster round the poles of the magnet. Again, when I shut off the current, the magnetism of the soft iron bar is lost as suddenly as it was acquired, and the nails fall down, in a heap, to the ground.

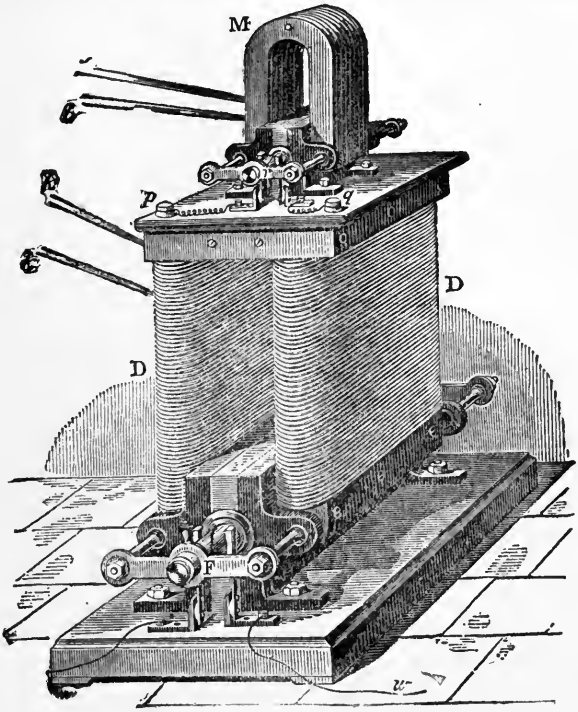
What you have chiefly to observe in this experiment is first, that an electro-magnet is far more powerful than a permanent steel magnet, of equal weight; and secondly, that it can acquire its magnetic power in a moment, and lose it in a moment. But I would ask you also to notice an incidental circumstance of the experiment, which though apparently trivial, has a singularly interesting application, as you will see by-and-by, in the Dynamo-Electric machine.

Observe that, although the great mass of nails has fallen down from the poles of the electro-magnet, there are one or two of the smaller nails still feebly clinging to it. To satisfy you that this is not a mere accident, I repeat the experiment again and again: each time, when the current is shut off, two or three small nails remain attached to the poles of the magnet. From this we may infer that, although the iron bar loses its magnetism, when the current ceases to pass, it does not lose it altogether; some faint traces still remain. This is called residual magnetism: and I ask you now to take a note of it. because you will see, a little later on, what an important part this residual magnetism will be called upon to play, in the development of our machine.

The idea of using an electro-magnet in the construction of a Dynamo was first carried out by Wilde of Manchester, in 1867. From the diagram before us, it will be seen at once that Wilde's machine consisted of two parts. The upper part is simply a machine of Siemens, such as I have just described to you. Here is a row of permanent horse-shoe magnets M, with two oblong masses of soft iron as pole pieces. Between these poles pieces a Siemens' aramature, one end of which is seen at *r*, is made to rotate by the belt *b b*.

The electric current generated in the armature, instead of being carried off to the external circuit, is conveyed from the binding screws *p q*, round the coils of a large electro-magnet D D, imparting to it a magnetic power far surpassing that of the permanent magnets above. Between the pole pieces of this electro-magnet, a second Siemens' armature, very much larger than the first, one end of which appears at F, is driven round by the belt *k k*, which is worked by a steam engine not shown in the sketch; and an electric current of great power is produced, which passes to the external circuit by the wires *w w*. This machine was first exhibited before the Royal Society of London in March, 1867, and afterwards at the Paris Exhibition in the summer of the same year, where it attracted very general attention.

A new Principle discovered.—But Wilde's machine was hardly finished when it was superseded by a new discovery, made about the same time by Dr. Werner Siemens, of Berlin, and Professor Wheatstone, of London. The practical result of this discovery was to show that the upper part of Wilde's machine was unnecessary; inasmuch as the current required to excite the electro-magnet can be obtained from



WILDE'S MACHINE, 1867.

M Row of Permanent Magnets.
b b Belt to drive Armature of Small Machine.
D D Large Electro-magnet.
k k Belt to drive Armature of Large Machine.
w w Wires to carry Current to external Circuit.

the action of the electro-magnet itself. At first sight, this statement looks like a paradox: we are to produce a current by means of an electro-magnet, and we are to make the electro-magnet by means of the current so produced. But the explanation is to be found in the phenomenon of residual magnetism, to which I called your attention a little time ago.

An electro-magnet, once excited, retains, for a considerable time, some faint traces of magnetism. Hence, if we suppose the upper part of Wilde's machine to be removed, and the armature in the lower part to be put in rotation, it would rotate, in fact, between the poles of a feeble electro-magnet, and accordingly a feeble current of electricity would be developed in the coils of the armature. Now this current may be conveyed round the coils of the electro-magnet, so as to increase its magnetic power, and thereby to increase the strength of the current developed in the armature. The same arrangement will convey this stronger current round the electro-magnet, thereby increasing still more its magnetic power, and increasing, at the same time, the strength of the current developed. And so the process may be continued, the power of the magnet and the strength of the current being rapidly exalted, until a certain maximum is attained at which the current is able to maintain the magnet at a high degree of magnetic intensity, and to do work in the external circuit as well.

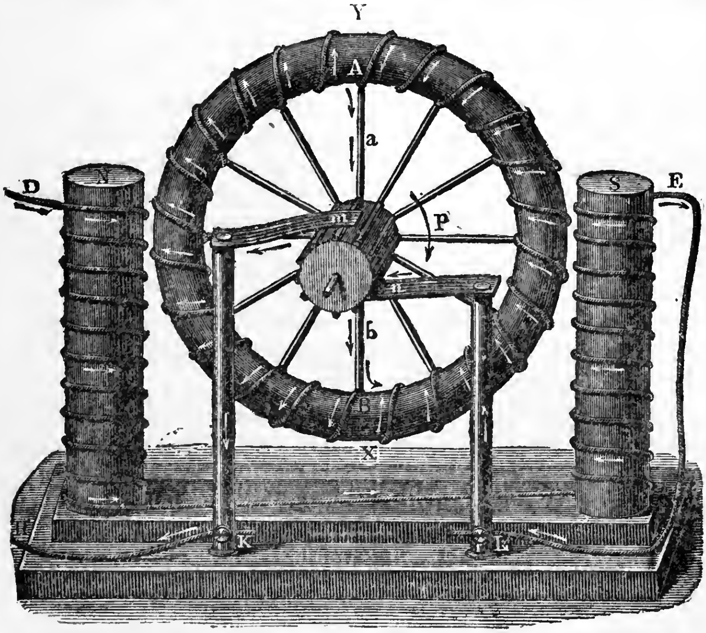
This principle, which was destined to bring about a revolution in the construction of Dynamo-Electric machines, was brought under the notice of the Academy of Science of Berlin by Dr. Werner Siemens, in the month of January, 1867, and in the following month of February it was brought before the Royal Society of London, by Professor Wheatstone, who had discovered it independently for himself. It soon received practical application, in a machine constructed by Mr. Ladd of London, which was exhibited at the Paris Exhibition in the summer of the same year.

But Ladd's machine, though it attracted a great deal of notice on account of the novel principle it embodied, never came much into practical use. It was followed, however, after a brief interval, by two machines, founded on the same principle, which may be said to mark an epoch in the history of our subject; I mean Gramme's machine, which was brought out in 1871, and Siemens' machine, which appeared in 1873.

It is worth while to dwell for a few moments on the construction of these two machines; for practically they furnish the types on which almost all the various forms of Dynamo machines have been since constructed. They differ from one another, chiefly in the way in which the insulated copper wire is wound on the armature, or rotating bobbin; Gramme having invented a new form of armature, and a new mode of winding the wire, while Siemens adopted a modification of the armature previously invented by himself, the construction of which I have already explained to you.

The Gramme Machine.—I think I can best give you a clear idea of the principle of the Gramme machine if I show you, in the first instance, not the machine itself, but an ideal skeleton, which exhibits all its essential parts, in their simplest form. In the diagram before you A B is a ring of soft iron, round which is coiled an insulated copper wire, with its ends connected together so as to form a continuous circuit. This ring can be made to rotate on its axis between the poles N S of an electro-magnet. How the magnetism of the electro-magnet is established and maintained I will explain by-and-by: for the present I simply assume that N and S are two magnetic poles, north and south respectively.

Now let the ring revolve in the direction of the arrow *p*. It may be shown, according to the principles established by Faraday, that as each spiral of the coil moves onward from X towards N a current of electricity is generated, which flows in the direction marked by the arrows: and again, as each spiral moves away from N towards Y, a current of electricity is also developed, and in the same direction.



IDEAL SKELETON OF GRAMME'S MACHINE.

AB Ring of Soft Iron.
NS Poles of Electro-magnet.
mn Copper Springs to collect the Current.

The Arrow *p* shows the Direction of Rotation.
The other Arrows show the Direction of the Currents.

Thus while the ring is revolving, as supposed, a force is developed which tends to make an electric current flow in that half of the ring which, for the time being, is on your left hand, from X upwards to Y. Similarly it may be shown that a force is developed in that half of the ring which, for the time being, is on your right hand, and this current too is from X upwards towards Y.

It is usual to conceive the action of these two forces as producing, on both sides of the ring, a gradual rise of what is called Potential between the spiral which, at any moment, is passing the point X, and the spiral which, at the same moment, is passing the point Y. Thus a Difference of Potential is maintained between the spiral which, for the time being, is at X, and the spiral which, for the time being, is at Y, the former being always at the lowest Potential, and the latter at the highest, of the whole coil. Now a Difference of Potential as regards electricity is like a difference of level as regards water. Water always tends to flow from a higher level to a lower level, and, when it flows, it is able to do work: so, too, electricity always tends to flow from a point of higher Potential to a point of lower Potential, and as it flows it is able to do work. Hence if a conductor of electricity be introduced between the spiral which for the time being is passing Y, and the spiral which for the time being is passing X, a current of electricity will flow through such a conductor, and may be used to do work as it flows.

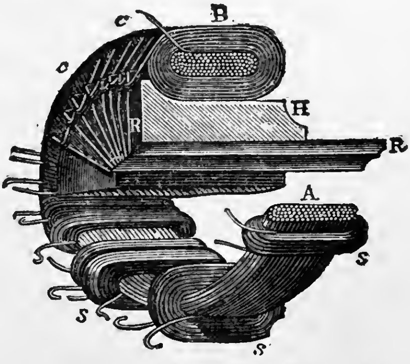
But how are we to introduce such a conductor, seeing that the spirals are all in motion, and that they are covered with an insulating material? The answer to this question leads us to one of the most ingenious devices of the Gramme machine. You will observe that every second spiral of the coil communicates with the axis of the ring, by means of a radius which is made of a good conducting material, and which connects the wire with a narrow copper plate, set edgeways in the circumference of the axis. Thus each of these little copper plates is, at every moment, in the same electrical condition as the corresponding spiral of the ring.

Now look at the two brass pillars in front of the ring. Each has attached to it a light copper spring. The one above, marked *m*, presses gently on the copper plate which is connected, through the radius *a*, with the spiral at the moment passing the point Y; the one below, marked *n*, is similarly pressing on the copper plate which is connected, through the radius *b*, with the spiral at the moment passing the point X. Hence the copper spring *m*, and the binding screw K connected with it, are always at the higher potential belonging to the spiral at Y; and similarly the spring *n* and the binding screw L are always at the lower potential belonging to the spiral at X. If, then, we connect K and L by means of a wire, a current will flow through the wire, and we can use it to produce the Electric Light, or to do any other kind of work.

Let us now come back to the Electro-magnet. I have hitherto assumed that it has magnetic power, all through the process I have described: it remains for me to show you how that magnetic power is imparted to it. At the outset, as I have already explained, the electro-magnet has some residual magnetism, which though feeble produces its due effect, and develops a feeble electric current in the rotating ring. This current is carried off to the external curcuit by the wire H, and coming back at D, is carried round the electro-magnet, so as to make N a stronger north pole, and S a stronger south pole, than they were before. The stronger magnetism develops a stronger current, and this stronger current, carried round the wire coils, increases still more the strength of the magnet; and so the strength of each is alternately increased, until, in less time than it takes to tell it, the maximumpower of the machine is reached.

Details of Construction.—This is the general principle of the Gramme machine, according to its simplest conception. In the machine itself, as will now be easily understood, the essential elements are: first, the electro-magnet; secondly, the ring armature; thirdly, the narrow copper plates set edgeways in the axis of the ring, which taken collectively are called the commutator; and fourthly, the copper springs, which convey the current from the commutator to the binding screws.

The electro-magnet is made of two massive bars of very soft iron, with pole pieces attached, which are so arched as partly to enclose the armature between them. The wire used for winding the electro-magnet varies indefinitely in length and thickness, according to the purpose for which the machine is intended. In the armature the soft iron core is not usually made of massive iron, as represented in the ideal sketch, but of thin iron wire, which is coiled into the form of a solid ring. This iron ring is then wound over with insulated copper wire, which is divided into a great number of sections, one end of each section being connected with one plate of the commutator, and the other end with the next plate. By this arrangement, as each section passes through the position of highest potential, that is, the position Y of the ideal sketch, the corresponding plate of the commutator will be at the highest potential; and in like manner, as each section passes through the position of lowest potential, the position X of the ideal sketch, the corresponding plate of the commutator will be at the lowest potential.

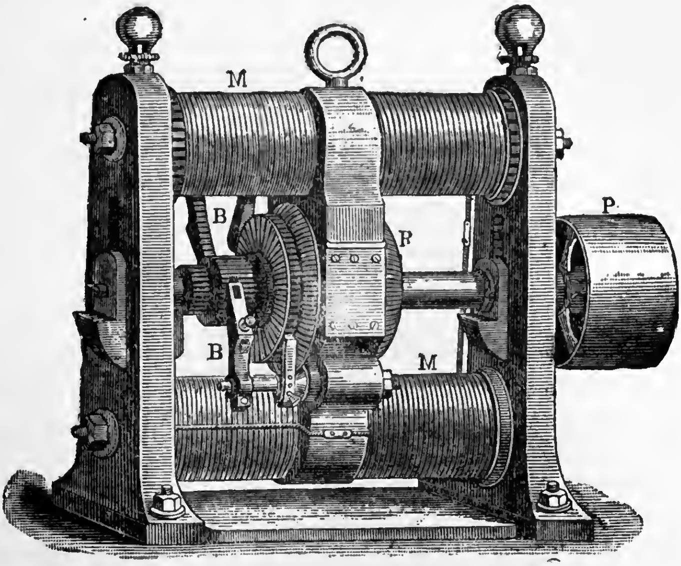


CONSTRUCTION OF THE RING ARMATURE.

A B	Cross section of the Ring showing the Coil, and the Iron Core within.	*s s*, *c c*,	Sections of the Coil.
		R R	Plates of the Commutator.
		H	Layer of Insulating Material.

The construction of the armature will be more fully understood by the aid of the diagram before you, which represents a Gramme ring cut across at one side, and partly opened out. At A and B are seen the cross sections of the iron wire forming the ring; *s s* and *c c* are the divisions, or sections as they are called, of the insulated copper wire, which is wound round the ring; R R represent the plates of the commutator, which are separated from one another by thin layers of some insulating material, shown at H. It will be observed that the sections of the coil are shown, in the lower part of the figure, separated out from one another, the ends of the wire in each section being left exposed; but in the upper part, the sections are shown as they actually exist in a working ring, closely pressed up together, and connected by the ends of the wire with the plates of the commutator.

The copper springs, represented by *m* and *n* in our ideal sketch, are now called the brushes, and consist in the smaller machines of a bundle of wires; but in larger machines they are generally made of thin copper plates. They are so adjusted that one is always pressing lightly on that plate of the commutator which, for the moment, is in the position of highest potential, and the other on that plate which for the moment, is in the position of lowest potential. Thus the electric current generated in the armature always tends to flow from one brush to the other, through any conductor that may offer it a passage; and the conductor is so arranged as to carry the current through the coils of the electro-magnet, where it maintains the magnetic power of the soft iron, and through the external circuit where it does work.



Gramme's Machine, Workshop Type, 1873.

M M Electro-magnets.
R Ring armature.
B B Brushes to collect Current.
P Pulley to drive Armature.

In the machine on the table, you will now easily recognize all the elements I have just described, built up into a compact and solid structure. It is an early form, though not the very earliest, of

Gramme's machine, and has done good service in its time: it is called the Type d'Atelier, or Workshop Type. These two massive horizontal bars, one above and one below, are the electro-magnets. The coils of the magnets are so wound that the poles are in the centre; and you can see the great pole pieces, one above and one below, arched as I have described them, and encircling a large part of the ring armature, which has just room to revolve between them. The armature itself is partly concealed from view; but enough is exposed to make it plainly visible, as I turn it slowly round between the poles of the magnet. On the axis of the armature you can see, too, the narrow edges of the commutator plates, which are here sixty in number. And lastly, here are the brushes, pressing lightly on opposite sides of the commutator, which collect the current and make it available for use in the external circuit.

This machine of Gramme's is curiously associated with the memory of the first Napoleon. On the tenth of November, 1801, or, as it was then called, the nineteenth Brumaire of the year X, a paper was read before the Institute of France, by the celebrated Volta. The subject of the paper was the well-known battery which he had just invented, and which has since been called, after him, the Voltaic Battery. The First Consul was present at the meeting; and being greatly struck by the prospects which the paper seemed to unfold, he offered a prize of 60,000 francs, to be open to the scientific men of all countries, and to be called the Volta Prize, for the best practical applications of the power of electricity.

This Prize was renewed by Napoleon the Third, by whom it was awarded three times, the amount, however, being reduced to 50,000 francs. It was again awarded under the Republic, in 1871, almost immediately after the close of the Franco-Prussian war. The last competition for it was opened in July, 1882, and closed in July, 1887; and on this occasion the Prize was awarded to Zénobie Théophile Gramme, for the invention of his Dynamo-Electric machines.

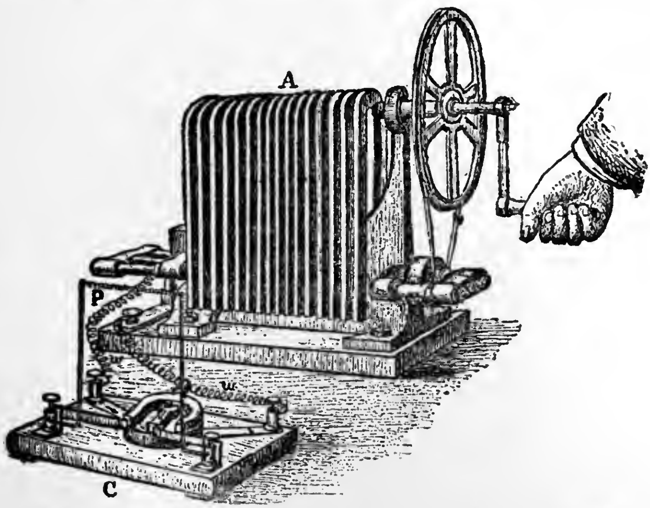
It is interesting to know that, even so late as 1862, M. Gramme was a working carpenter in the employment of Rumkorff, a well-known maker of philosophical apparatus in Paris. He had no scientific training; but having been engaged to finish the woodwork of some electrical machines, he was fascinated by the mysterious power with which he found himself brought into contact, and by the sheer force of native genius and indomitable perseverance, he achieved the great triumph of constructing a machine which marks a new epoch in the history of the industrial arts.*

I will not trouble you any further with details of construction. The machine invented by Siemens of Berlin differs from Gramme's machine only in the way of winding the armature: and the great

* See The Electrician, July 27, 1888, p. 364; and August 24, 1888, pp. 496, 497.

majority of machines now made follow, in the main, one or other of these two types. Though the modifications and improvements introduced, during the last fifteen years, are countless in their variety, yet the same essential elements are common to all machines. There is the armature, or rotating bobbin of wire; there are the massive electro-magnets; there is the commutator, with its numerous copper plates, set edgeways on the axis of the revolving armature; and there are the brushes, which collect the current from the armature, and send it round the coils of the electro-magnet and into the external circuit.

The Dynamo does not Create Energy.—Before closing this branch of my subject, I should wish to remind you that the Dynamo does not create the electrical energy it sends forth. It is a law of nature that the sum total of the energy in the material universe, remains always the same: it suffers no loss, and it receives no accession. It is given to man to use it as he pleases; but, in using it, he can only change it from one form to another: he has no power to increase the store, or to annihilate any part of it. We cannot, therefore, get a stream of electrical energy to flow from our Dynamo unless we expend some other kind of energy in producing it; and the energy so expended must be always proportional to the electrical energy we want to produce.



EXPENDITURE OF ENERGY IN PRODUCTION OF ELECTRIC CURRENT.

A Early Form of Siemens' Machine.
w w Wires conveying Electric Current.
C Commutator for closing and breaking the Circuit.
P Platinum Spiral.

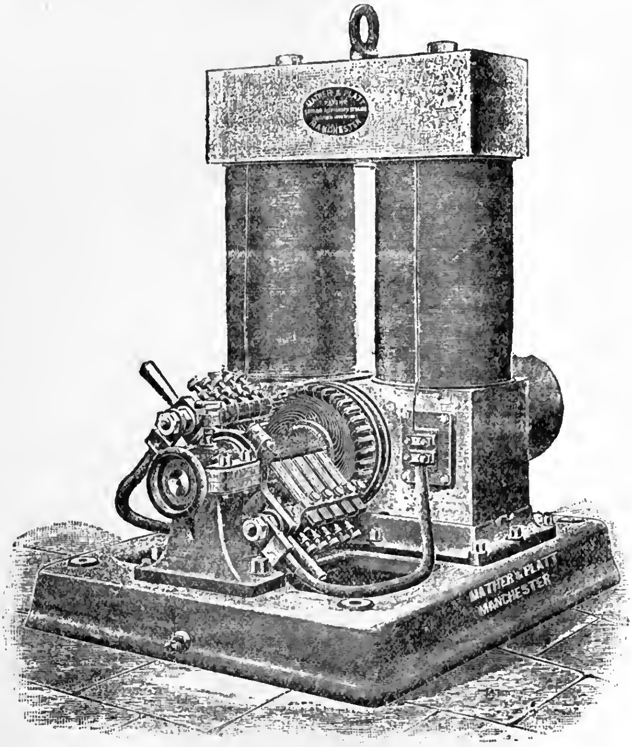
Let me try to bring this important truth home to you by an experiment. Here is a good-sized specimen of one of the earliest forms of Siemens' machine. It is a machine with permanent magnets, such as I have already described, and is made to be worked by the hand, the armature being driven round by means of this wheel. The binding screws of the machine are connected by light flexible wires with the commutator on the table; and, by turning the handle of the commutator, I can complete the circuit through this platinum spiral, or I can interrupt the circuit, just as I please. When the circuit is interrupted, no current is produced, no matter how fast the bobbin of wire may be forced to rotate; but when the circuit is complete, a current is at once developed in the rotating bobbin, and flows through the platinum spiral.

Now what I want you to observe is this. When the circuit is interrupted, and no current is produced, the bobbin of wire is driven round with ease: it is only necessary to impart a certain velocity of rotation to a comparatively small mass of matter, and to overcome the friction of the machine. But when the circuit is closed, and the bobbin can no longer continue to rotate without producing an electric current, then a far greater amount of labor must be expended to drive it. This is the fact you have to observe: and with this fact before your eyes you will readily admit the inference, that the additional work done, when the circuit is closed, is the mechanical equivalent of the electrical energy produced.

My assistant will now turn the wheel. The circuit is at present interrupted, and you see with what ease he makes the bobbin fly round at a rapid rate. I turn the handle of the commutator: the circuit is now closed. It is like putting on a break: every one can see how much harder my assistant has to work to keep the bobbin going; and, at the same time, the platinum spiral begins to glow with a bright red light, which shows that a current is passing. I reverse the motion of the handle: my assistant is, at once, relieved; and the little platinum lamp goes out, showing that the current has ceased to flow. I close the circuit once more: once more he is obliged to use all his efforts to force the bobbin round; and once more the glowing of the platinum lamp tells us that the additional work expended has resulted in the production of an electric current.

Electrical Energy produced in Dynamo is due to Mechanical Energy expended.—We learn then that the electrical energy developed in a Dynamo is the product of the mechanical energy expended in driving it. It follows that the electrical energy developed can never exceed the mechanical energy expended. Practically it is always less; because a certain portion of the mechanical energy goes to overcome the friction of the machine, and is therefore converted directly into heat, and not into electrical energy. A portion, too, of the electrical energy developed is expended within the machine itself, and is not available for practical use. But notwithstanding the loss of energy, arising from these two causes, so great is the perfection to which the Dynamo has now been brought, that from eighty to ninety per cent of the work done in driving the machine is sent forth in the form of electrical energy, and may be turned to useful account for Electric Lighting, and for other kinds of work.

The diagram before you, which represents the machine known as the Edison-Hopkinson Dynamo, made by Messrs. Mathers and Platt of Manchester, will give you a good idea of the modern Dynamo, in one of its finest forms. In this machine the electrical energy available for the external circuit is stated to be over ninety per cent of the mechanical energy applied to drive it, and is capable of maintaining more than a thousand incandescent lamps of sixteen candle-power each.



THE EDISON-HOPKINSON DYNAMO.

I have now brought to a close the first part of my subject. I have endeavored to present to you, in a rapid sketch, the history of the Dynamo, from the first discovery of the fundamental principles on which it is founded, down to the present time; and I have tried to make you realize that, with all its varieties of form and detail, it is, in its essence, simply a machine for converting mechanical energy into the energy of an electric current. In my next Lecture I will try to show you how the energy of the electric current is converted into light.

LECTURE II.

HOW THE ELECTRIC CURRENT IS MADE TO YIELD THE ELECTRIC LIGHT

WHEN an Electric Current passes through a conductor, the conductor is heated; and if the current is strong enough, and the conductor is suitably chosen, it can be raised to a very high temperature, and made to shine with a bright light. This phenomenon may be shown, in its simplest form, by means of a spiral of platinum wire, such as is mounted on this little stand before you.

Simplest Form of Electric Light.—I first turn on the current from two cells of a Storage Battery, in the next room: the platinum spiral is sensibly hot to the touch, but there is no glow of light. I add three cells more, and the spiral gets red. I increase the number to eight, and it now emits a pure white light of great brilliancy.

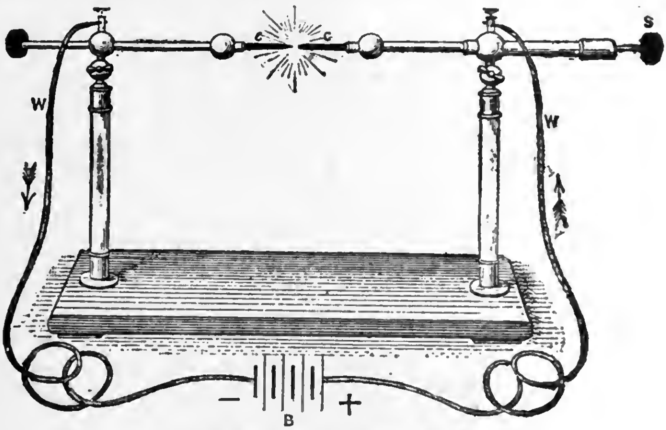
You will expect, perhaps, that I should explain the nature of the process by which heat is thus produced in this wire while the current is passing through it. That is a matter, however, which is not yet perfectly understood. We do not know what the electric current is, in itself; much less do we know what is the nature of the process that goes on in the wire, when, as we say, the current is passing through it; and therefore we cannot really explain how the heat is produced. But we are not altogether ignorant on the subject: we know a little, and that little is easily told. We know that an electric current has energy; we know that it encounters resistance in the platinum spiral, that it overcomes that resistance, and that, in doing so, it expends a part of its energy; and we know that the energy so expended is converted into heat.

Let me illustrate these fundamental conceptions by a familiar example. Every schoolboy knows that if he takes a brass button, and rubs it very hard against a deal board, he can make it so hot that he can hardly bear to touch it. Now, where does this heat come from? You will probably say, "Oh, we know all about that; that's friction." Well, you are quite right: but what is friction? It is a kind of force existing between the surface of the brass button and the surface of the deal board, and tending to prevent the one sliding over the other. But in spite of that force the schoolboy makes the button slide to and fro; in doing so he expends muscular energy: the energy so expended passes away from him forever; and in its stead the energy of heat appears in the brass button and the deal board.

Now we may conceive that the resistance offered by this platinum wire to the electric current is a kind of *electrical friction;* and that the electrical energy expended in overcoming that resistance is converted into heat, just as muscular energy is converted into heat in the familiar experiment of the schoolboy.

An electric lamp, then, is nothing more nor less than a contrivance to convert the energy of an electric current into the energy of heat. It must consist of a conductor which, while it allows the current to flow through it, offers nevertheless a considerable resistance to its passage: and the conductor must be of such material that, when raised to a high temperature, it will glow with light.

Electric Light first produced, 1810.—The Electric Light was first produced by Sir Humphry Davy, at the Royal Institution of London, in the year 1810. He employed a battery of 2,000 cells, and he connected the poles of the battery, by means of a stand like this before you, with two carbon rods, which were mounted on the stand. When the two carbon rods were first brought into contact, and then



SIR HUMPHRY DAVY'S EXPERIMENT.

B	Battery	C C	Carbon Rods.
W W	Wires from Battery to Carbons.	S	Adjusting Screw.

slowly drawn asunder through a short distance, the current leaped across the intervening space of air, and at the same moment the carbons were intensely heated, and shone with a light of dazzling brilliancy.

I can show you this experiment on a small scale. In the next room there is a battery of twenty-six cells, and the poles of the battery are connected, by these two conducting wires, with the two carbons which you see mounted on the frame before you. At present the carbon points are half an inch asunder, and no current is passing. But by turning a screw provided for the purpose I can bring them into contact: they are now touching, and the red glow that you see at the point of contact shows that the current is flowing. I next reverse the movement of the screw, separating the carbon points by about a quarter of an inch, and a brilliant star of white light fills the space between them.

This experiment of Sir Humphry Davy attracted universal attention, and awakened a general expectation that so brilliant a light would soon be turned to useful account as an ordinary means of illumination. But the expectation was not destined to be quickly realized. The Voltaic Battery, which was the only means known at that time, and for many years afterwards, of producing an electric current, was too costly and troublesome for general use: and although the Electric Light has long been familiar to scientific men as a useful means of research and illustration, it is only since the development of the Dynamo-Electric machine, within the last twenty years, that it has emerged from the obscurity of the laboratory, and passed into the wider domain of everyday life.

Two Types of Electric Light.—You will observe, from the experiments I have already shown you, that there are two different methods of producing light from an electric current; in fact, two different types of electric lamp. In the experiment of Sir Humphry Davy, the solid conductor is interrupted, and a narrow stratum of air interposed in the path of the current. The light produced in this way is called an Arc Light. In the case of the platinum spiral there is no interruption in the circuit: the solid conductor is continuous throughout, and a portion of it is made to glow as the current passes through. The light so produced is called an Incandescent Light.

These names are not very happily chosen. The Arc Light is so called from its supposed resemblance to the form of an arc. But the resemblance is more fanciful than real; and, in any case, it is quite a secondary feature in the character of the light. Again, the Incandescent Light has no special claim to that title; because both forms of light are really incandescent, both being produced by the glowing or incandescence of the heated conductor. But life is too short to quarrel about names: and having put you on your guard against any misunderstanding that might arise from the use of these terms, I will take the names as I find them, the Arc Light and the Incandescent Light, and I will tell you something about each.

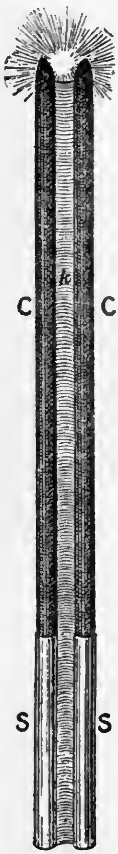
The Arc Light.—Let me begin by repeating again the experiment of Sir Humphry Davy, which gives us, as I said, what is now known as the Arc Light. I first turn the screw to bring the carbon points into contact; then I reverse the movement, separating them by a short space, and the light at once bursts forth. But observe, after a few moments, when the apparatus is left to itself, the light gets dim and eventually goes out. The reason is that the carbon points are slowly consumed in the intense heat generated by the current; the distance between them is thus gradually increased; as the distance increases, the resistance offered to the current is likewise increased, and the current gets feebler; at last the resistance becomes so great that the current ceases to pass, and the light dies out.

Hence it is necessary, if we want to maintain the light for any length of time, to keep the carbon rods so adjusted that, notwithstanding the waste that is always going on, they shall remain, nevertheless, at practically the same distance apart. In the apparatus before us such an adjustment may be made by means of this screw, which enables me slowly to advance one of the carbon rods, as the space between them is increased by the process of slow combustion. But when the light is wanted for practical purposes, it is evidently desirable that the adjustment should be made by some kind of mechanism, which shall work of itself without the intervention of any external agency.

Duboscq's Lamp.—Such a piece of mechanism was first invented by Foucault of Paris, and was afterwards improved by Duboscq. It is commonly called Duboscq's Electric Lamp. I have it here on the table; and I will try to give you a general idea of the principle on which it works. The carbon rods, as you see, are so fixed in these brass sockets that they are both in the same vertical line, one pointing upwards, the other downwards, with a short distance between them. The lower carbon is permanently connected with the positive pole of a battery or Dynamo, and the upper carbon with the negative pole. Within the case of the lamp there is a clockwork arrangement, which you can see through this glass plate; and when the clockwork is set going, the carbons are made to approach each other. When they come into contact the current passes. At the same moment, an electro-magnet within the case is magnetized by the current, and attracts a small iron bar, which is held suspended by a spring just above the poles of the magnet. The effect of this is twofold. First, the movement of the iron bar pulls asunder the carbon points through a short distance, and starts the light; secondly, it pushes in a small knife edge against a toothed wheel, and stops the clockwork.

As the light continues to shine, the carbon points are slowly consumed by the intense heat. The distance between them is thereby increased, and the current gets feebler. Now the electro-magnet, being fed by the current, gradually loses its strength as the current gets feebler, and relaxes its hold of the iron bar. At last, it can hold it no longer, and the iron bar is pulled up by the spring, the strength of which is carefully adjusted beforehand. When the iron bar is pulled up the clockwork is set free, and the carbon points again begin to approach. As they come nearer to one another, the current gets stronger, and the magnet, regaining its force, pulls down the iron bar again, and stops the clockwork. Since this process may go on indefinitely, the light will be maintained until the current is cut off, or the carbons are burned away.

New Forms of Automatic Lamp.—So long as the Electric Light was confined to the laboratory and the lecture hall, this lamp of Duboscq, in one form or another, held almost undisputed possession of the field. But the recent development of the Dynamo-Electric machine gave a new impulse to invention; and there are now before the world a countless variety of lamps suitable for the production of the Arc Light. You may see them, of various shapes and forms, at the railway stations and in the public squares of nearly all the capitals of Europe, and they are distributed even more abundantly over the great continent of America. Some of them, no doubt, leave much to be desired in point of steadiness and certainty of action; but many of them, on the other hand, work with a degree of smoothness and precision which almost justifies the enthusiastic descriptions by which they are heralded into public notice. I will not trouble you with the details of their construction. Enough it is to say that they all aim at the same end, namely, to keep the carbon points at a constant distance from each other, notwithstanding the fact that they are always wearing away by combustion.



THE JABLOCHKOFF CANDLE.
C C Carbon Rods.
k k Insulating Layer of Paste.
S S Brass Sockets to be connected with Battery or Dynamo.

But no matter how perfect the mechanism of these lamps may be, the Arc Light is always, from its very nature, an unsteady light. The distance between the carbon points first increases as the carbons are consumed, then it is diminished when the mechanism comes into play, then it increases again; and so on, indefinitely. Now every change in the distance between the carbons produces a change in the resistance of the arc; and every change in the resistance of the arc produces a change in the intensity of the light. Thus the light is, of necessity, constantly varying in intensity; and the highest aim of inventors has been to reduce such variation within the narrowest possible limits. Absolute steadiness of the light seems hardly attainable: the most that can be hoped for is a near approximation to steadiness.

The Jablochkoff Candle.—About twelve years ago, a great sensation was produced by the introduction of a new form of Arc Light, under the name of the Jablochkoff Candle. Monsieur Jablochkoff was an officer in the Russian army; but as soon as he conceived the idea of his Electric Candle he resigned his commission, and came to Paris. Here he took out a patent for his Candle, opened a workshop for the manufacture of it, and in a few months made himself famous as the inventor of a new form of Electric Light.

I have here a few specimens of the Candle. It consists, as you see, of two carbon rods, about ten inches long, placed parallel to one another, and kept at a distance of about a quarter of an inch all along their length, by a solid layer of white pasty matter which acts as a non-conductor. The composition of this paste is an important feature in the manufacture of the Candle: various substances have been tried at different times; but I believe the most effective is now found to be a mixture of baryta and plaster of Paris. The carbon points project about a quarter of an inch beyond this insulating layer; and a small bridge of some conducting material is laid across, to enable the current to pass from one to the other.

When the Candle is mounted for use, one carbon is put in connection with the positive pole of the dynamo or battery, by means of the brass socket in which it is fitted; and the other carbon is similarly put in connection with the negative pole. The current, not being able to force its way across the insulating layer that separates the two carbons passes up through one, then across the bridge, and down the other. The bridge is at once consumed by the heat generated and the Arc Light is started between the two points. In the intense heat of the Arc, the insulating layer is melted and consumed; and the whole Candle burns slowly away in the course of about two hours. The intensity of the light is equal to from two to three hundred candles.*

There is an interesting little bit of scientific history connected with this invention. Jablochkoff had read in text-books on Electricity that the positive carbon is consumed twice as fast as the negative; and he said, "I will provide for that by making my positive carbon twice as thick as my negative, and so they will burn down evenly together." He accordingly made his Candles, in the first instance, with one thick and one thin pencil of carbon; the thick pencil being always connected with the positive conductor, and having twice as great a sectional area as the thin one.

But this ingenious device did not stand the test of practical experience. On the one hand, the positive carbon did not burn away exactly at the rate which had been calculated upon; while, on the other hand, the negative carbon, offering a greater resistance to the current, became red hot along a considerable portion of its length, and was thus sensibly reduced in thickness, by slow combustion at its surface. Owing to these causes the Candle was found to burn very irregularly, and generally went out at the end of about a quarter of an hour.†

The first Candles then were a failure. But the inventor soon found another resource. You may remember I explained, in my last Lecture, that a dynamo can give us currents alternately in opposite directions, or currents continuously in the same direction, according to the mode of its construction. Jablochkoff, then, conceived the idea of using a machine which would give currents alternately in opposite

*For a full account of the Jablochkoff Candle, see the elaborate work just published by Hippolyte Fontaine, Eclairage à l'Electricité, Paris, 1888, pp. 376--381.

† Id. *ib.*, p. 377.

directions. Thus each carbon would be alternately positive and negative: they would therefore be equally consumed, and if made of exactly the same thickness they would burn down evenly together.

This new Candle at first promised to be a great success. It was taken up in Paris, and used instead of gas along the whole length of the Avenue de l'Opéra, as well as on the Place du Théâtre Français, at one end, and the Place de l'Opéra, at the other. In London, too, it was adopted on the Thames Embankment, from Charing Cross Station to the House of Parliament. But it failed to fulfil the high hopes which it had awakened. Perhaps the clearest evidence of its failure is that they have taken down all the Electric Candles on the Avenue de l'Opéra, and I am sorry to say have gone back again to gas.

The cause of the failure is due, I think, in great measure, to the insulating layer of paste. When the current passes across from carbon to carbon, this paste is melted and vaporized, and produces a sort of flame with a varying tinge of color. Moreover, there seems to be a constant change of resistance, according to the condition of the paste, at any given moment; and this gives rise to a great unsteadiness in the light. At all events, whatever the cause may have been, the Jablochkoff Candle, though at first received with great enthusiasm, has been generally found unsatisfactory; it has been almost completely abandoned in England, and it is not likely to be heard of much more in the history of Electric Lighting.

I should say, however, that the Electric Candle still seems to find favor in France. According to the most recent accounts it is still manufactured, in that country, at the rate of a million and a-half a-year. At Havre, it is used to illuminate the port; and in Paris, . is familiar to all visitors, at the Magasins du Louvre and the Magasins du Printemps. It appears that, between these two establishments, somewhere about 465 Jablochkoff Candles are in daily use. But in the more famous mart known as the Bon Marché, which has recently been fitted up with one of the finest Electric Light installations in the world, there are only 96 Electric Candles, while there are 290 Arc Lights of the ordinary kind, and 1808 Incandescent Lamps of the Edison type.*

The Incandescent Light.—I now come to speak of the Incandescent Lamp. In this form of lamp, the conductor through which the current flows is continuous: that is to say, there is no point in the circuit where the current has to leap across a stratum of air, as in the Arc Lamp. But the resistance of the circuit is so adjusted as to be concentrated on some one part of the conductor, which is thus made to glow with intense heat, when the current passes. The simplest example of such a lamp is the platinum spiral which I have already shown you, and which, I may say, has been before the world

*See Eclairage à l'Electricité, par Hippolyte Fontaine, Paris 1888, pp. 380, 544–551.

for nearly fifty years. The current, coming from a battery of ten cells in the next room, is here conveyed for the most part through a stout copper wire, which offers little resistance, and is therefore only slightly heated: but, at a certain point in the circuit, a spiral of platinum wire is interposed in the path of the current, for a space of two or three inches. The platinum wire offers considerable resistance; intense heat is therefore produced in this part of the circuit; and the wire glows with a rich white light.

This platinum spiral is, in some respects, a very perfect little lamp. Platinum has no tendency to combine with oxygen, even when raised to a high temperature, and no matter how often it is made incandescent, it is not consumed. It glows with light when the current passes; and it returns to its former state when the current is shut off. One would almost think that a lamp of this kind should last for ever. But it has one fatal defect. Every metal has its own melting-point, that is to say, a certain definite temperature at which it will melt. The melting-point of platinum is estimated at about 2,000 degrees centigrade; and to yield a really good light it must be raised to the very verge of melting. Hence, in order to get an effective light from incandescent platinum, we must keep it so close to its melting-point that a slight irregularity of the current may, at any moment, cause it to melt, thus breaking the continuity of the circuit, and extinguishing the light.

I should like to bring this point home to you by an experiment, though the experiment involves the sacrifice of my lamp. At present the current flowing through this spiral is carefully regulated, to make it glow with a fairly good white light. But I can increase the strength of the current, either by adding more cells to the battery, or by cutting out some resistance from another part of the circuit. The latter method is the more delicate, and the more convenient for our purpose. You see on the wall a rectangular frame containing twelve stout carbon rods. This is called a resistance-board. At present these carbon rods are part of the circuit, so that the current must flow through them all, one after another. But by turning a handle, I can cut out two or more at pleasure, and so reduce the resistance by small degrees.

I now turn the handle, and cut out two carbon rods. The resistance is slightly reduced, the current becomes stronger in proportion, and you see the platinum spiral shines with increased brightness. I advance the handle another stage, and cut out two more carbons. The platinum spiral is more brilliant still; but its brilliancy lasts only for a moment; its melting-point has been reached; the circuit is broken; and the light disappears.

You will say, perhaps, that we might avoid this danger if we contented ourselves with a less brilliant light. Quite true: but that is just what we will not do. Having once seen what a brilliant light the electric current can give us, we will not be content with a platinum spiral that gives us only the light of two or three candles. Hence, after many ingenious attempts of Mr. Edison to produce an effective lamp, first with platinum alone, afterwards with an alloy of platinum and irridium, this form of lamp has been reluctantly abandoned, at least for the ordinary purposes of illumination.

Carbon versus Platinum.—Now the property that platinum wants is possessed in a very high degree by carbon. I have already said that carbon cannot be melted by any kind of artificial heat yet known. Hence it was recognized long ago that, if we could substitute for this platinum spiral a slender rod of carbon, we might raise it to the most brilliant incandescence without any fear of melting it. But unfortunately carbon has another property which would be fatal to such a lamp. It would not melt, but it would be consumed. Carbon, when raised to a high temperature, has a great affinity for oxygen; and if our carbon lamp were exposed to the air, as we have exposed our platinum lamp, the carbon, when raised to incandescence, would combine with the oxygen of the air, to form carbonic acid, and would be burned away in a very short time.

The remedy for this defect is easy to see, and was tried so long ago as the year 1845, by an American inventor named King. He got a thin pencil of carbon, mounted it on a frame within a glass vessel, and then exhausted the air from the vessel, by a process similar to that by which a Torricellian vacuum is produced in a barometer tube. This lamp, however, was a failure. The carbon pencil received the electric current by means of a metal rod passing through the glass vessel; and sufficient air soon found its way through the joint thus established to cause the combustion of the carbon.

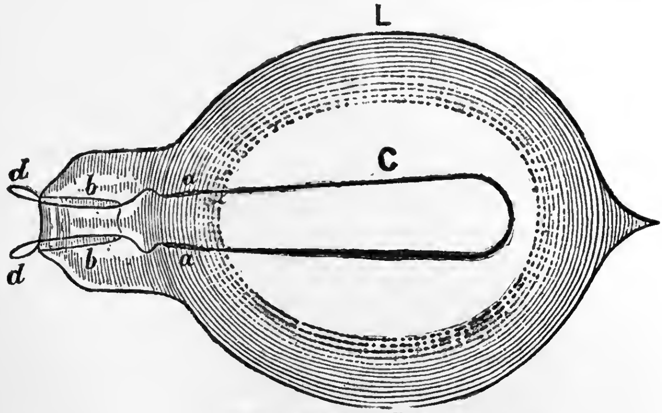
I may say that practically no progress was made with this form of Electric Light, from the time of King until the year 1879, when Mr. Edison of New York, and Mr. Swan of Newcastle, startled the world by the production of those beautiful incandescent lamps which are inseparably associated with their names. Other inventors quickly appeared in the field; numerous patents were taken out; and various claims to priority were advanced. I need not dwell upon these claims, or on the controversies to which they have given rise. It is enough to say that the incandescent lamp, which had awakened such hopes, and such fears too, when first announced to the world, was rapidly brought to a high degree of perfection; and by the time of the Paris Electrical Exhibition, in 1881, it was already fully established as a magnificent success.

A Perfect Vacuum.—The name of Mr. Crookes of London is not often mentioned in connection with electric lighting; and yet Mr. Crookes has contributed, in no small measure, to the production of the incandescent lamp in its present form. The lamp consists of a thin filament of carbon mounted in a glass globe from which the air has been exhausted. In its essential principle, therefore, the lamp does not differ from the lamp invented by King forty years ago. But King's lamp failed for want of a good vacuum; and Mr. Crookes is the man to whom we are mainly indebted for the almost perfect vacuum of the modern lamp. The history of this matter is interesting and curious.

Mr. Crookes was engaged, between the years 1873 and 1878, in making experiments with his well-known radiometer. For these experiments he required a vacuum far more perfect than any which had been previously known. He therefore applied his rare powers of invention and contrivance to the improvement of Sprengel's mercurial air-pump. And so great was his success that we are now in possession of an air-pump which, with ease and certainty, can reduce the density of the air within a glass globe considerably below the millionth of an atmosphere.

With such a vacuum placed at their disposal, the difficulties in the way of inventors, occupied with the development of the Electric Light, were already half conquered: and accordingly it is not wonderful that, between the year 1878 and the year 1881, a number of different lamps, with more or less claims to originality of invention, should have been brought into public notice. The most successful of these lamps were those of Mr. Edison and Mr, Maxim in America, and of Mr. Swan and Mr. Lane-Fox in England.

Incandescent Lamp with Carbon Filament.—The essential elements of an incandescent lamp, as now made, are a thin filament of

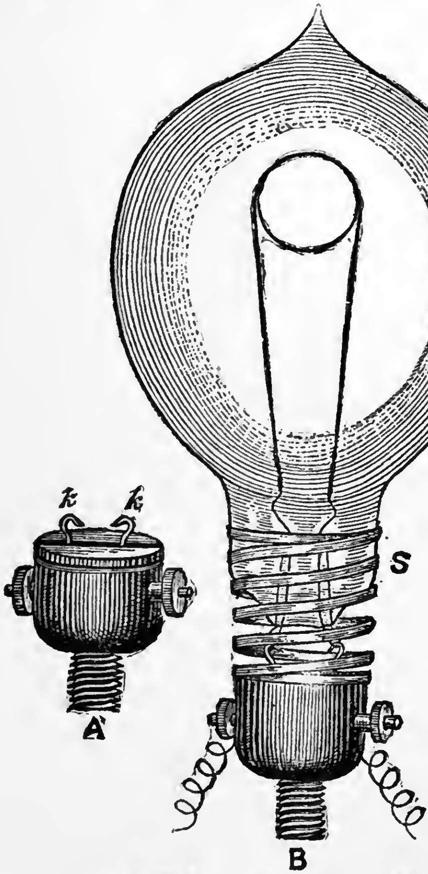


THE INCANDESCENT LAMP.

L Glass Globe exhausted of Air.
C Thin Filament of Carbon.
b b Platinum Wires attached to Carbon Filament at *a a*, and looped outside the Glass at *d d*.

carbon, a glass globe, and a perfect vacuum. Here is one of the most recent construction; but you will see the details more distinctly on the diagram before you. L is the glass globe from which the air has been almost completely exhausted: C is the carbon filament; *b b* represent the platinum wires, which pass through the glass, and are formed into loops outside at *d d;* and *a a* show the points of attachment connecting the carbon filament with the platinum wires.

In order to connect the platinum wires with the opposite poles of a Dynamo or Battery, it is usual to provide for each lamp what is called a Holder. The Holder of the Swan lamp, which you see here on the table, and which is also represented in the diagram on the wall, is

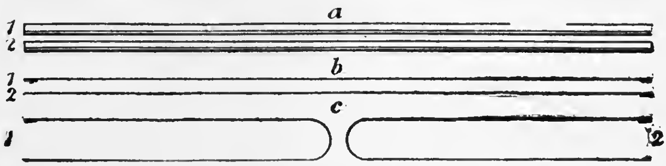


INCANDESCENT LAMP AND HOLDER.

A Holdre showing Hooks at *kk*· | B Lamp on Holder showing Spring at S.

extremely simple. It consists of a button of ebonite or hard wood, with two binding screws, to which the wires from the Battery are attached, and which are themselves connected with two hooks, *k k*. You see how easily the lamp may be fitted on to these hooks, by means of the platinum loops which are left exposed outside the glass globe. But to secure more perfect contact, a spiral spring is interposed between the Holder and the lamp, which tends to push them away from one another, and thus maintains a steady pressure at the points of contact. I now take a lamp and fit it on to the Holder, and you see it ready for use.

Preparation of the Carbon Filament.—Next to the vacuum, which is now always produced by one form or other of the mercurial air-pump, the most important feature in the lamp is the carbon filament. This filament is variously made. The most essential property, recognized by all, is that it should be of uniform thickness and uniform structure throughout its whole length, so that it shall offer, at every point, exactly the same resistance to the passage of the current. Mr. Edison after numerous experiments with a great variety of vegeta



PREPARATION OF FILAMENTS FROM BAMBOO CANE.

a Flat Strips of uniform Character.
b The same narrowed down to thickness of a thread.
c The same bent into Shape and ready for Carbonization.

ble fibres, selected the bamboo cane as the most suitable for his purpose.

Having first removed the hard silicious outer coating, he prepares a number of strips perfectly flat and straight, of the required length as shown in the diagram at *a*. Each of these he shaves down to a uniform thickness along its whole length, with instruments which he has specially devised for the purpose. He then narrows them to the fineness of a thread, leaving a small projecting piece at each end. They are thus reduced to the condition shown at *b* in the diagram. Lastly, these fine threads of bamboo fibre are bent into shape as shown at *c*, and fitted into moulds to be carbonized.

Mr. Swan, in the first instance, used cardboard as the material from which he manufactured his carbon filament; afterwards he tried bibulous paper, which he treated with dilute sulphuric acid; but he finally settled down to ordinary cotton thread as giving the most satisfactory results. He steeps the cotton thread in dilute sulphuric acid, giving it thereby somewhat of the character of parchment, then twists it into the shape required, and prepares it for carbonization. This is the process, I believe, now commonly followed by the Edison-Swan Company. The carbon filament produced by it is said to be very tough, and as hard and stiff as a metallic wire.

In the process adopted by the Anglo-American Brush Company, cotton wool is the material employed. It is first dissolved in chloride of zinc, and being slightly heated is reduced to a viscous or semi-fluid condition. It is then forced through a small orifice under the pressure of a head of mercury, and, coming out in a thread-like form, is received in a vessel of alcohol, where it solidifies. Lastly, it is placed in another vessel of alcohol, which dissolves all impurities; it is then dried and carbonized.*

The process of carbonization is practically the same for every kind of filament. The vegetable fibre, having been prepared in any of the various ways above described, is packed in powdered charcoal in a closed vessel, and then gradually raised to a white heat, at which it is kept for several hours.

When the carbon filament is ready for use, the ends of it are carefully attached to the ends of two platinum wires, and it is introduced into a glass globe, the neck of the globe being raised to a melting temperature and closed in round the platinum wires, so as to form a perfectly air-tight joint. It only remains then to exhaust the air from the globe, which is done by means of a glass tube, which serves to connect it with a mercurial air-pump.

During the process of exhaustion a current of electricity is sent through the carbon filament, which is thereby raised to incandescence, and freed from the air and other gases that might otherwise have remained shut up within its pores. When the exhaustion is complete, the tube connecting the globe with the air-pump is removed, and the orifice in the globe is closed in the blow-pipe flame.

Light without Heat?—There are some questions of practical interest connected with the Electric Light on which I should wish to say a few words, before bringing this Lecture to a close. First, I may notice a general impression which seems to prevail that, in the case of electric illumination, we have light without heat. Now I have shown you that, in both forms of the Electric Light, the carbon becomes luminous simply because it is made intensely hot. You have seen, in fact, that when a platinum wire is used instead of a carbon filament, in the incandescent lamp, there is danger of melting the wire, though its melting-point is somewhere about 2,000° C., which is higher than that of any other metal.

Again, in the arc lamp, the heat of the carbon points is absolutely the greatest artificial heat known. To give you some idea of this intense heat, I turn on the current to this arc lamp on the table, and now when I hold a stout platinum wire close to the positive carbon, it melts like sealing wax in a candle flame. A steel rod, held in the same position, sends out a brilliant shower of sparks in all directions. It is therefore an error to say that in either kind of electric lamp we have light without heat.

Nevertheless, there is an important germ of truth in the common

*It is interesting to note that this process has been the subject of a protracted law-suit, in which the Edison-Swan Company were the plaintiffs, and the Brush Company were practically the defendants. It was contended on the part of the Edison-Swan Company, that they had the exclusive right to manufacture lamps with carbon filaments. But the learned judge refused to admit this claim, and gave judgment in favor of the Brush Company. The history of the incandescent lamp was very fully brought out during the progress of the trial, and is set forth with great clearness in the luminous judgment of Mr. Justice Kay. See The Electrician, May, June, July, 1888.

belief. If you look closely at the filament of an incandescent lamp, you will see that, although three or four inches in length, it is exceedingly thin. It has, therefore, a very small volume: the volume of an ordinary gas flame is probably several hundred times as large. Hence though the intensity of the heat in the filament, that is, its temperature, is very great, the quantity of heat is comparatively small. It has been estimated that, for the same amount of illumination, a gas flame gives out more than fifteen times as much heat as an incandescent electric lamp, and wax candles more than twenty-five times as much. Similarly in the case of the arc light, the incandescence of the carbon points is confined to a very small volume, and the quantity of heat generated is proportionally small.

The Arc Light and the Incandescent Light compared.—Next, perhaps, you would like to hear some opinion as to the relative merits of the arc lamp and the incandescent lamp. I would say that each is excellent in its way; but they are suited for quite different purposes. First, let me say something of their relative cost. For a given expenditure you can get eight or ten times as much light from the arc lamp as you can from the incandescent lamp. Every horse-power in your engine will maintain about eight incandescent lamps, giving a light of sixteen candles each, or say a hundred and thirty candles in all: whereas the same power with an arc lamp will give an average light of a thousand to twelve hundred candles.

The arc light, however, is quite unsuited to the interior illumination of houses. It is too dazzling and it is too unsteady; perhaps I should add that, owing to the predominance of blue and violet rays in the arc light, it gives a weird and haggard appearance both to people and to things. On the other hand, it is admirably fitted for all kinds of illumination out of doors; for the illumination of streets and railway stations, of public gardens, docks, and harbors, in a word, of all places where people congregate or work is to be done.

The incandescent lamp comes in most efficiently just where the arc lamp fails. It gives a rich soft light in which brilliancy and steadiness are combined, and is admirably suited for interior illumination. It is pre-eminently the light for public institutions of every kind; museums, libraries, and picture galleries, hotels and theatres, shops and factories; and I may say it is the ideal light in private houses and on ship-board. Let us compare it, for a moment, with the other modes of illumination at present in use.

Comparison with other kinds of Light.—Every other artificial source of light, whether gas, or candles, or oil, takes out of the air the oxygen which is necessary for the support of life, and gives back, in return, carbonic acid, which tends to produce suffocation: whereas the incandescent lamp takes nothing from the air, and it gives nothing to it but pure and simple light. Again, the incandescent lamp produces far less heat, as we have seen, for a given amount of illumination, than other sources of light. Once more, oil and candles and gas often produce a disagreeable smell, and always produce more or less smoke, which discolors the walls and ceilings of your rooms, injures your paintings and the bindings of your books, and disfigures every kind of decorative work. The incandescent lamp produces no smoke, and what to many is, perhaps, even more important, it produces no smell.

A very remarkable testimony to the healthfulness of the incandescent lamp, as compared with gas, was given by Mr. Preece, at the Meeting of the British Association recently held in Bath. About two years ago, the Electric Light was introduced into the Central Post Office Saving Bank, in London; and since that time, the leaves of absence, on account of illness, of members of the staff, have been reduced by an amount equal to an average of two days a year for each person. This, he said, was equivalent to a gain to the service of the time of eight clerks, and represented a saving of about £640 a-year in salaries.*

As regards the danger of fire, it is not easy to exaggerate the extraordinary safety of the incandescent lamp. I would only call your attention to one fact. In dealing with gas and candles, we are dealing with a naked flame, whose function it is to set fire to whatever touches it; in the case of the incandescent lamp, we are dealing with a light shut up in a prison house of glass, and if we chance to break the glass, we at the same moment put out the light.

Is the Electric Light now available for use?—But the most important practical question still remains behind: Is the Electric Light at present really available for use, so that we may have it, if we choose, without reasonable fear of disappointment? This is a question I must answer in parts; and I would ask you to remember that I express only my own opinion, founded on such information as I have had access to. First, as regards the arc light, it is perfectly available for all purposes of out-of-doors illumination; and you can have it when you please, with certainty, with efficiency, and with economy.

Secondly, with respect to the incandescent light, I would say it is available for every public institution and for every private house that is large enough, or rich enough, to afford the expense of a separate installation. Where a large number of lights, say one or two hundred, are required for several hours every day, I believe that a separate installation may be set up and maintained with economy, as compared with other modes of illumination. Hence I hope to see the Electric Light established here in our new Museum and in the National Library, as well as in the National Gallery and the Museum of Natural History. This splendid group of buildings, designed to be a great centre of education and culture for the people, offers a field for the

* See Address to the Mechanical Section of the British Association 1888, by W. H. Preece, F.R.S., President of the Section.

introduction of the Electric Light which, so far as I know, stands almost unrivalled.

In like manner, an Electric Light installation may be established with economy in factories and workshops, in theatres, clubhouses, and large hotels. In private houses, on the other hand, where the number of lights required would be less that a hundred, a separate Electric Light installation would probably be found more costly that other means of illumination. But it would be a luxury: and I can say, with confidence, that this luxury is now available for every one who may wish to have it, and can afford to pay for it.

Lighting from a Central Station.—So much for separate installations. A question of still wider interest has probably suggested itself to most of you: Is it possible to supply the Electric Light to all the houses of a given area, from a central station, as gas is now supplied? This is a problem which is just now the subject of experiment on a large scale: and when a practical question has been submitted to the test of experiment, it is wiser, I think, not to prophesy until we know the result. I may tell you, however, what has been already done. About two years ago, a central station was established close to the Grosvenor Gallery, in London; and, at the present moment, this station supplies electric currents for about 30,000 incandescent lights, scattered over an area of somewhat more than a mile radius. This is the largest experiment of the kind, so far as I know, that has yet been carried out in England; but how far it may be regarded as a practical success it is impossible to judge until we know, upon sufficient authority, the exact facts connected with the working of the system.

Transformations of Energy.—And now, in conclusion, let me remind you, even at the risk of repetition, that in setting before you this slight sketch of the history and development of the Electric Light, I have given you, at the same time, as I believe, a striking illustration of those wonderful transformations of energy that are forever going on around us, both in the operations of Nature and in the works of man. In my last Lecture, I sought to bring home to you that the Dynamo is nothing more then a machine for converting the energy of mechanical motion into the energy of an electric current: and in my Lecture to-day I have shown you that the various forms of electric lamp are only so many contrivances for converting the energy of the electric current into the energy of heat and light.

If I were to trace back the history of these transformations farther towards their source, we should find that the mechanical energy which drives the Dynamo is derived from the stored-up energy of coal; and the coal comes from the vegetation of a long past time; and that ancient vegetation was quickened into life by the energy of the sun's rays. Thus it would seem that this beautiful light, which the Science of our time has called forth to illuminate our streets and our houses, does but bring back to us the energy of the primeval sun, which for long ages appeared to be lost, but was in fact carefully stored up for our use; and the saying of the Roman poet, "Omnia mutantur nihil interit," receives a deeper and a fuller meaning than even he himself would probably have attached to it.

Beacon Lights of Science

THE STORING
OF
ELECTRICAL ENERGY

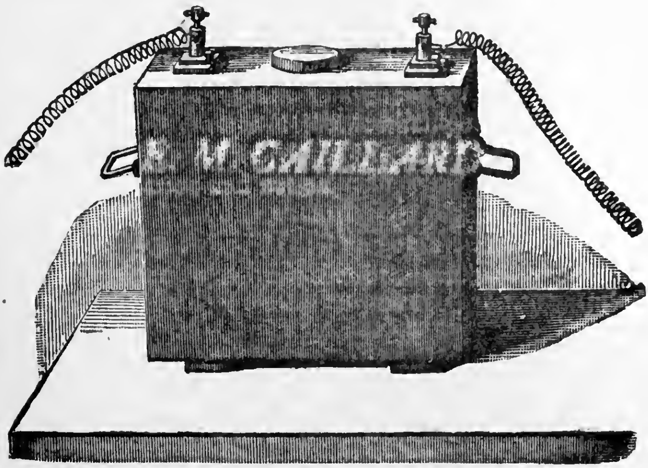
A LECTURE

DELIVERED IN THE THEATRE OF THE ROYAL DUBLIN SOCIETY

MARCH, 1882

THE STORING OF ELECTRICAL ENERGY.

IN the early part of last summer, an account was published in The Times newspaper of a "marvellous box of electricity," one cubic foot in size, which, it was said, had been carried from Paris to Glasgow, and there deposited in the laboratory of Sir William Thomson. A few weeks later, a letter appeared from Sir William Thomson himself, stating that he had carefully examined the box; that he had found it to contain a million foot-pounds of energy; and then when this store was exhausted, it could be easily renewed, so as to be again

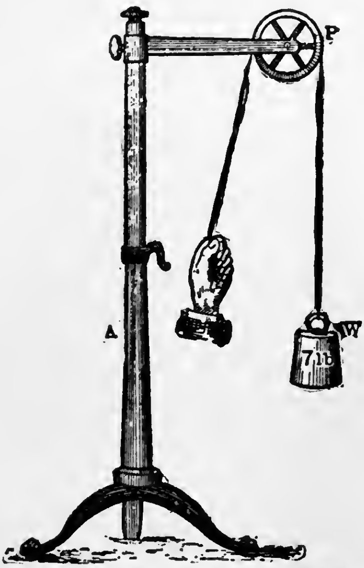


The "Marvellous Box of Electricity."

ready for use. Further, he told us, in effect, that a few of these boxes, laid by in a cellar, might be charged from time to time from a central factory, and might be used as occasion required, either to drive machinery, or to light up a drawingroom. With the aid of such boxes, a tramcar might dispense with horses, and a railway train with steam engines. Nay, he said, the vast energies of the Falls of Niagara might be stored up in these wonderful boxes, and used as the chief source of light and power for the whole continent of North America.

These statements are, perhaps, tinged with the glow of enthusiasm, naturally excited in a great mind, when it contemplates the first dawn of a new discovery, and glances forward, by anticipation, to its future history. But the simple facts of the discovery, even when expressed in the sober words of science, are quite sufficient to account for the wide-spread interest it has awakened. This "box of electricity," as it has been called, is nothing more or less than a kind of store, in which electrical energy is laid by, so to say, and kept ready for use when wanted. Its practical value can be fully determined only by actual trial: but this much may be said, even now, that it gives fair promise of bringing more completely under our control one of the most potent and mysterious forces of nature.

My object to-day is to give you some account of this new discovery; to tell you what it is in itself, and how it stands in relation to our previous knowledge; how it comes opportunely, as it were, to fill a vacant place, and puts it in our power to deal with the energy of the electric current as we have long been accustomed to deal with other forms of energy.

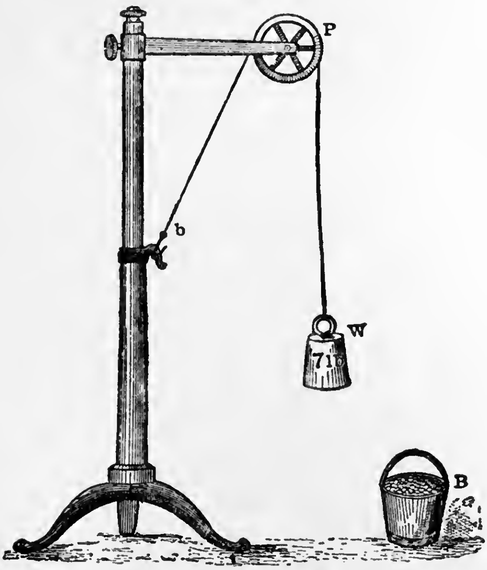


ENERGY EXPENDED IN DOING WORK.

A Stand supporting the Pulley P. | W Weight of 7lbs., lifted up one foot.

Example of Energy Stored up.—At the outset, let me try to bring home clearly to your minds what is meant when we speak of storing energy. Energy is the capacity of doing work; and it is measured by the amount of work that is done when the energy is expended. Here is a weight of seven pounds resting on the table. It is tied to one end of a string which passes over a pulley. When I pull down the other end of the string, I pull up the weight, say to a height of one foot. In doing so, I expend a certain amount of energy, and I do a certain amount of work. If I call the work done, when a pound weight is lifted one foot high, a foot-pound, then the work done, when a weight of seven pounds is lifted one foot high, will be seven foot-pounds; and this is the measure of the energy I have expended in pulling up the weight before you.

Now I want to show you that the energy so expended is stored up in the weight, so long as it remains in the position to which I have raised it. You know that if I leave the weight to itself, it will fall back to the table, and that in falling back it is able to do work: therefore, in virtue of its present position, it has the capacity of doing work; that is, it has energy. I may store up that energy indefinitely, by



ENERGY STORED UP IN A SUSPENDED WEIGHT.

A Stand supporting the Pulley P.
B Bucket filled with Shot.
W Weight kept suspended by the Hook *b*.

simply hooking on the string to this stand, so as to keep the weight suspended at a height of one foot from the table. But, on the other hand, I may draw upon my store of energy whenever I please, and use it to do work. Here is a little bucket of shot, which weighs somewhat less than seven pounds. I hook it on to the free end of the string, and then let go. The weight falls down one foot, and the bucket of shot goes up one foot.

If we consider the work done, by the falling weight, on the bucket of shot, we shall see that it is a little less than seven foot-pounds, since the bucket of shot weighs somewhat less than seven pounds. But the falling weight has done another kind of work: it has overcome the friction of the pulley. And moreover, when it reached the table it had still a little energy left, which is expended in a feeble blow. Now, if we were to measure the energy of that blow, and add it to the energy spent in overcoming friction, and add both, taken together, to the work done on the bucket of shot, the whole would be equal to seven foot-pounds of work; and thus we should find that our weight, in falling back to the table, did work which is the exact equivalent of the energy I had expended in pulling it up. In this sense, the energy expended by me may be said to have been stored in the uplifted weight.

You will find an interesting illustration of this principle in a common eight-day clock. The works of the clock are driven by the weights; and the weights, in doing their work, are always falling slowly towards the ground. When at length they can fall no further, they can do no more work, and the clock is said to have run down. If we want to set it going again we must wind it up; that is, we must lift up the weights into a position from which they can fall down again. In doing so, we expend muscular energy, and the energy so expended is practically stored up in the weights, to be given out slowly and continuously, in the form of work, as they fall back towards the ground, during a period of several days.

In like manner, when you wind up a watch, you lay in a store of energy, by coiling up an elastic spring; and the spring expends this energy in doing work, as it slowly uncoils itself, and imparts motion to the wheels of the watch. Again, when I pump air into this air-gun, I lay up a store of energy in the form of compressed air; and I can draw upon that store at pleasure, and use it for the purpose of discharging bullets from the barrel of the gun.

It would be easy to multiply examples; but my object is not so much to treat this branch of the subject exhaustively, as to suggest familiar illustrations of a general principle. Everyone can supply new examples from his own experience. Thus a steam-hammer lifted up has a store of energy, which it expends, in doing work, when it falls, by its own weight, on the anvil. A cross-bow stretched has a store of energy, which is ready at any moment to send an arrow flying through the air. A cannon-ball discharged from the mouth of a cannon has energy stored up, which does work in tearing asunder the massive armor of an iron-clad vessel. The fly-wheel of a gas-engine receives, at each explosion, a store of energy, which it expends in keeping up the movement of the machinery until the next explosion comes.

Energy Stored up in Clouds and Rivers.—Sometimes energy is stored up for us by a natural process, and we have nothing to do but to use it. You have seen that there is a store of energy in an uplifted weight, and that we may use this energy for the purpose of doing work, as the weight falls back to its former level. But it may not have occurred to you that Nature is always busy, laying up for us a store of energy of this kind, which is practically inexhaustible. She is always lifting up the water of the ocean in the form of vapor, and setting it down again on the summits of our hills and mountains, in the form of rain and hail and snow. There it gathers into rivulets, and the rivulets coming together form streams, and the streams sweep down into the valleys, and flow back as stately rivers to the parent ocean. And all along its course, this falling water, as you know, has within it a store of energy, which it is ever ready to give out in doing work for us—in grinding corn, or in sawing timber, or in driving machinery.

Energy Stored up in Coal-Mines.—So much for the storing of what may be called mechanical energy. I should now wish to give you one or two illustrations of the way in which the energy of heat may be stored up. I need not tell you how largely the energy of heat is employed, in the form of steam, to do the work of the world. Now we get this heat, as a general rule, by the combustion of coal; and therefore a coal-mine is a vast store of energy, always available to drive our machinery and to do our work.

Here, again, we are indebted to the beneficent foresight of Nature. Long ages ago this store of energy was laid up for us, in the primeval forests of that ancient time which is known to geologists as the Carboniferous Period. The rich and luxuriant vegetation of those primeval forests was mainly composed of certain chemical compounds of carbon and hydrogen, which were drawn off from the air and the earth by the action of natural forces, and built up into the structure of plants and trees. Ages rolled by; generation after generation of that ancient life flourished and decayed; the dry land was submerged beneath the ocean; new strata were spread out over the sunken forests; and by a slow and gradual process the vegetation of that long-past time was compacted into beds of coal. But after all these changes, the hydro-carbon compounds, built up in the primeval forests, still survive in the coal, and constitute, in fact, the source of all the heat that is given out when coal is burned.

It is worth while to pause for a moment, and consider the actual process of combustion by which this heat is developed. Hydrogen has a great natural attraction for oxgyen, and so has carbon. In consequence of this attraction they are ready, under certain conditions, to part company with one another, and to combine, each of them, with oxygen, thus forming new chemical compounds. When we light a fire we produce the required conditions, and the process then goes on until all the coal is burned away. The hydrogen combines with oxygen, and forms water; the carbon combines with oxygen, and forms carbonic acid. Thus the coal is converted, by combustion, into water and carbonic acid; a small quantity only, which is incombustible, remaining behind in the form of ashes.

But what is the physical cause of the heat produced in this process? You remember that a weight in falling to the ground, under the attraction of gravitation, can do work for us. If, however, it be allowed to fall without doing work, it reaches the ground with its full store of energy unimpaired, and expends it all in a single blow. Now it has been fully demonstrated by experiment that, by this blow, the energy of the falling weight is converted into the energy of heat. And it would seem that the heat produced in combustion is generated by a somewhat similar action. The atoms of hydrogen and carbon clash with the atoms of oxygen, and heat is evolved in the collision. In the case of a fallen weight, a mass of sensible magnitude, moving through a sensible distance, strikes against another mass; in the case of combustion, millions upon millions of minute atoms, moving through indefinitely small distances, strike against each other. But in both cases alike, the energy of moving bodies is converted into the energy of heat.

Energy Stored up in Separated Gases.—And now we can see more clearly what it is exactly that makes coal a store of heat energy; it is the fact, that in coal we have carbon and hydrogen, on the one hand, existing apart from oxygen, on the other, with a chemical force acting between them, and tending to pull them together. Proceeding from this idea, it is easy to conceive how we can lay up for ourselves a store of this kind of energy. Water, as you know, is a chemical compound of oxygen and hydrogen. Now, on the table before you is a voltaic battery, and near the battery is a glass vessel containing acidulated water. When I send a current of electricity from the battery through the water, the molecules of water are pulled asunder by the action of the current, and resolved into their constituent elements. You can plainly see the gases as they rise in multitudes of bubbles, in these two glass tubes, which are now brilliantly illuminated by a beam of light from the lantern. The oxygen is set free in the tube to your left, where the current enters the liquid; the hydrogen in the tube to your right, where the current leaves the liquid.

What I want you to observe, in this beautiful and interesting experiment, is, that we are here expending a certain kind of energy—the energy of an electric current—in doing a certain kind of work, that is, in pulling asunder the atoms of oxygen and hydrogen against the force of attraction, which tends to keep them locked together in close chemical union. The two gases, thus forcibly separated, have a strong tendency to combine again. and when they do combine, they will generate new energy in the form of heat.

To impress this important fact distinctly on your minds, I will now get these gases to combine chemically before you. You see on the table, side by side, two small bags, one filled with oxygen, the other with hydrogen. And here is an apparatus known as the oxy-hydrogen lamp. It has one tube connected with the bag of oxygen, another with the bag of hydrogen. The two tubes communicate, by means of these stop-cocks, with the same common jet, where I mean to bring the gases into intimate contact, under circumstances favorable to their chemical combination.

First turning one of the stop-cocks, I allow the hydrogen to flow out, and when a lighted taper is applied to the jet, the hydrogen burns with a pale blue flame. This flame, though but faintly luminous, is intensely hot, as I can easily show you. Here is a spiral of platinum wire, and you see, when it is held in the flame, it at once begins to glow with a steady white light. The heat that is here produced is due to the combination of the hydrogen, coming from our bag, with the oxygen present in the air around us. But it becomes far more intense when I turn the second cock, and thus pour a stream of pure oxygen into the jet of glowing hydrogen. To give you some practical evidence of the heat that is now yielded up by our store of energy, I take this piece of steel wire and hold it in the flame. See how it burns away like tinder, and scatters about a shower of brilliant sparks. I put aside the wire, and in its stead I hold a rod of chalk in the burning jet. The chalk does not burn, but it glows with intense heat, and sends forth a light of almost overpowering splendor.

These are pretty experiments, and in many ways instructive. But for our present purpose I would ask you to fix your attention on one point only: that all the heat and light, produced in the flame of our lamp, is due to the clashing together of the hydrogen and oxygen atoms, under the force of chemical attraction. Now they never could have clashed together, unless they had first been pulled asunder. And therefore, in pulling them asunder, we gave them the capacity of producing that heat and light.

This is the sense in which the energy of heat may be said to be stored up in these two bags of oxygen and hydrogen. In the same sense it is also true that the energy of heat is stored up in a piece of coal. And in a similar sense, as we have seen, there is a store of mechanical energy in an uplifted weight, in a running stream, in a stretched cross-bow, in a cannon ball shooting through the air.

Storing of Electrical Energy not a New Idea.—Having now before us, as I trust, a clear conception of what is meant by the storing of mechanical energy, and the storing of heat energy, we may pass on to the subject of more immediate interest, the storing of electrical energy. It will, perhaps, be a surprise to some of you, to hear that the storing of electrical energy is not a new idea, but one that has long been familiar to the minds of scientific men. When a common electric machine is put in action, electrical energy is stored for a short time in the prime conductor, and is given out whenever a spark passes. It is stored, too, and more effectively, in a Leyden jar, when the Leyden jar is charged from the machine. And Nature, I need hardly tell you, has a way of her own for storing electrical energy in a thunder cloud.

Again, it may be said, with perfect truth, that every voltaic battery is a store of electrical energy. In a voltaic battery, some metal is employed, generally zinc, which, when the battery is working, is acted on chemically by an acid. The effect of this chemical action is that the atoms of the metal combine with the oxygen of the acid; and by the act of combination an electric current is generated. Now observe how closely this process resembles the process by which heat is developed from coal. In the case of coal, we have carbon and hydrogen existing apart from oxygen, with a chemical force tending to make them combine, under suitable conditions. We set up these conditions when we light a fire: the chemical force then comes into action the carbon and hydrogen rush to meet the oxygen; and in the clash of atoms heat is developed. Similarly, in the voltaic battery, we have zinc existing apart from oxygen, with a chemical force tending to pull them together. We bring this force into action when we arrange the cells of our battery, and make the necessary connections; the atoms of zinc and oxygen then clash together, and, by the energy of their collision, an electric current is generated.

Thus it is clear that, exactly in the same sense in which heat energy is said to be stored in a lump of coal, it may also be said that electrical energy is stored in the zinc plates of a battery. It is worth observing, too, that both cases furnish a striking illustration of a universal law of Nature. We cannot use our store of energy, and keep our store, at the same time. We cannot get heat from coal, except by a process in which the coal is burned, and ceases to exist as coal. And so, too, we cannot get an electric current from our zinc plates, except by a process in which the zinc is gradually consumed, and ceases to exist as zinc.

But you will ask me, If every voltaic battery is practically a store of electrical energy, how is it that the discovery of a means of storing electrical energy has caused so great a sensation within the last twelve months? Is it to be said that we are able to do no more, with the aid of this new discovery, than we were able to do without it? I have led up to this question, because I want you to understand what it is precisely that this new discovery promises to do for us.

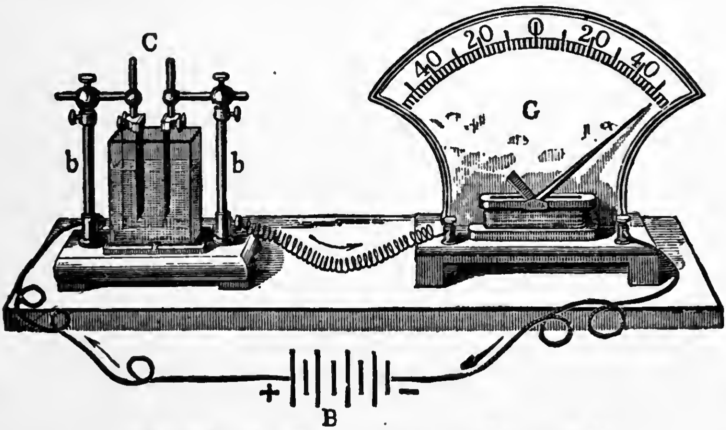
First, then, let me tell you that, although an ordinary voltaic battery is a store of electrical energy, it is an expensive store. To get an electric current from the battery we must, as I have just told you, consume the zinc plates, and zinc is an expensive metal. Speaking roughly, I may say that it costs about twenty times as much as coal, weight for weight. Again, the arrangements that must be made, in order to get an electric current from the zinc, involve the use of other costly materials, such as nitric acid and sulphuric acid; they also involve the constant attendance of skilled hands. Hence it was found out, long ago, that the voltaic battery, however useful it may be in a scientific laboratory, or on certain special occasions, when cost is a matter of little moment, cannot be employed with advantage to supply electricity, on a large scale, for public use.

The Storage Battery.—Now the new discovery—the storage battery, as it has been very naturally called—differs from the ordinary voltaic battery in this, that it does not, of itself, give us an electric current, but it gives us a means of storing the energy of an electric current obtained from some other source. Thus you see, at once, that it would be of no practical use unless we had at hand some cheap and convenient way of producing electricity. But this want has been most opportunely supplied within the last few years. The dynamo-electric machines, which have now been brought to so high a degree of perfection, place at our disposal a supply of electricity which is at once very cheap, and practically unlimited in amount. In fact, it is the rapid and extraordinary development of these machines that has brought into such prominence, at the present moment, the question of using electricity as one of the ordinary agents of light and power.

This question, I need hardly say, is surrounded by many difficulties, some of which have been partially overcome, and some have yet to be encountered. But it is agreed, on all hands, that few difficulties would remain unconquered, if, having got a cheap supply of electrical energy, we could now cheaply store it up, in a convenient form, and keep it ready for use, as occasion might require. This is a problem eminently attractive to the man of science, and not less attractive to the practical man of business; and it is because the new storage battery seems to give fair promise of solving it, that it has created so great a sensation, and awakened so wide an interest.

The object of this battery is simply to make an electric current store up its own energy, in a form suitable for future use; and I will now try to give you some idea of the way in which this object is attained. We have already seen that when a current of electricity, coming from a voltaic battery, or from any other source, passes between two metal plates immersed in acidulated water, the water is decomposed by the action of the current, oxygen being set free at the surface of one plate, and hydrogen at the surface of the other. As a result of this decomposition, a new force is set up within the liquid, which opposes the passage of the current, and tends to produce a current of its own, flowing in the opposite direction. If now the battery current is cut off, and the two metal plates are connected by a wire, outside the liquid, this new current will begin to flow, and to produce electrical phenomena in the circuit thus formed. The electric current obtained in this way is called a secondary current, to distinguish it from the current coming from without, which is called the primary current.

Experiment to show Secondary Current.—I should like to demonstrate to you by experiment the existence of this secondary



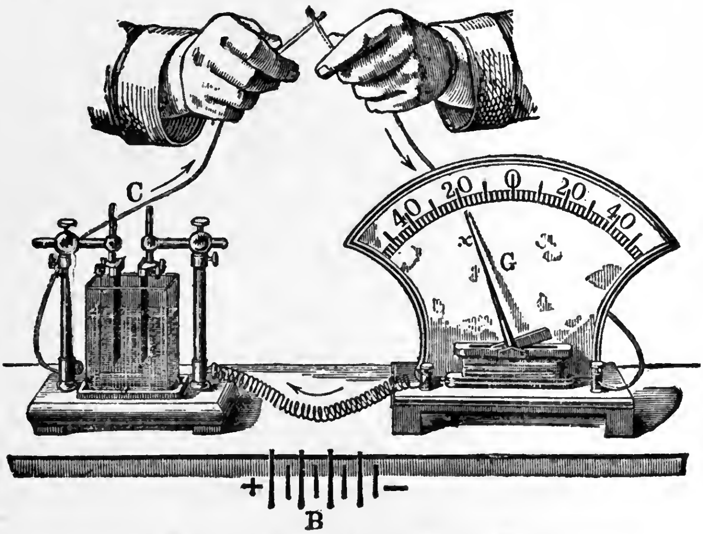
DECOMPOSITION CELL: PRIMARY CURRENT FLOWING.

C Decomposition Cell.
b b Brass Pillars.
G Galvanometer.
B Battery.
x Index of Galvanometer, deflected to the right.

current. Here is a glass cell containing acidulated water. Plunged in the water you can see two metal plates: one is connected, by this brass pillar and a flexible wire, with the positive pole of a battery; the other is connected, by a second brass pillar and another wire, with one of the binding screws of a lecture-table galvanometer; and the second binding screw of the galvanometer is conected with the negative pole of the battery. By this arrangement the current from the battery is made to pass first through the acidulated water in the glass cell, and then through the galvanometer. When I put the battery in action, observe how the index of the galvanometer is at once deflected, showing that the current is passing. At the same moment bubbles of gas begin to appear in the glass cell, showing that the process of decomposition is going on. After the lapse of a few seconds, I break the circuit, and cut off the battery current. The bubbles of gas are no longer developed, and the index of the galvanometer returns to zero.

Let us now try if the glass cell, with its metal plates, can give us a current of its own. For this purpose I will take the wire coming from the first metal plate, and bring it into contact with the wire attached to the second binding screw of the galvanometer. The circuit will then be the same as it was in the first part of our experiment, with this difference only, that the battery is left out. When I make contact, mark how the index of the galvanometer is deflected, proving that a current has begun to pass; and observe, too, that it is deflected not to your right, as it was before, but to your left, showing that the direction of the current, from the cell, is opposite to that of the current which came from the battery.

Now I want you to see clearly, before we proceed further, that this is a case of energy stored up. The energy of the primary current was first expended in doing a certain work, that is, in decomposing the molecules of water. As a direct consequence of this work, we had oxygen and hydrogen existing apart, with a chemical force acting between them, and tending to pull them together. This was our store of energy; and we drew upon the store when we cut off the



SAME CELL: SECONDARY CURRENT FLOWING.

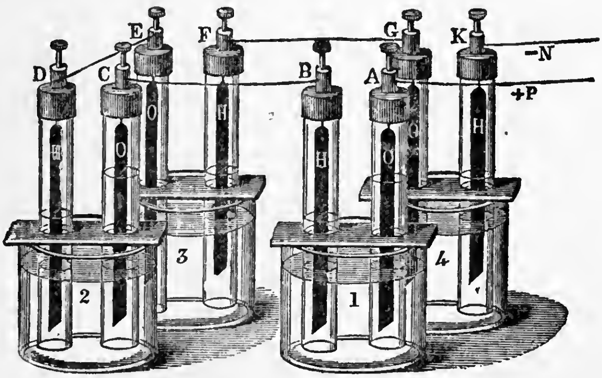
C Decomposition Cell.
G Galvanometer.
x Index of Galvanometer, deflected to the left.

battery, and completed the circuit between the two plates of the decomposition cell. The chemical force was thus brought into action, the oxygen and hydrogen began to combine again within the cell, and in the act of combining they yielded an electric current.

I have dwelt at some length on this simple and familiar experiment, because it exhibits in a very clear light the fundamental principle of storage batteries. Some chemical change is produced within the storage cell, by means of a current of electricity which is made to flow through it; and in virtue of this change, the cell has a store of energy which it is ready to yield up, under suitable circumstances, in the form of an electric current. It remains for me now to describe briefly the principal attempts that have been made to apply this principle to practical purposes.

Ritter's Secondary Pile.—The earliest form of storage battery was made just eighty years ago, in Germany, by Ritter, of Jena. He took two small circular discs of copper, and between them he placed a similar disc of cloth, steeped in acidulated water This combination constituted one element of his battery. He made a second element of the same kind, and laid it down on the first; a third, and placed it on the second; and so on, until he had built up a pile, or column, consisting of fifty or sixty elements. He now sent an electric current through the pile, from top to bottom; the water in the discs of cloth was decomposed, a counter electro-motive force was set up in each element, and when the battery was cut off, the pile yielded, for a short time, an electric current of considerable power. This battery is known as Ritter's Secondary Pile; but as the current lasts only for a few minutes, it is of little practical use.

Grove's Gas Battery.—Forty years passed away, and Ritter's secondary pile was almost forgotten, when a new form of secondary battery was devised by Sir William Grove, who was, at the time, Professor of Experimental Philosophy in the London Institution, and is now one of the Judges in the High Court of Justice in England. His plan was to combine together a series of decomposition cells, such as



Grove's Gas Battery.

1, 2, 3, 4, Cells of the Battery.
A B, C D, E F, G K, Glass Tubes closed at the Top, and filled with acidulated Water.
P Wire by which the Charging Current enters the Battery.
N Wire by which the Charging Current leaves the Battery.
O Strips of Platinum Foil at which Oxygen is set free.
H Strips of Platinum Foil at which Hydrogen is set free.

the one with which we have just been making our experiments. Into each cell he introduced two glass tubes, closed at the top, and filled with acidulated water. Every tube contained a long strip of platinum foil; and when the primary current was sent through the series of cells, it entered each cell by one platinum plate, and passed out by the other.

An arrangement of this kind, consisting of four cells, is on the table here before you; and you will observe that now, when I send the primary current through, crowds of little bubbles appear in every tube, while the galvanometer, which is also in circuit, indicates by its deflection that a strong current is passing. After a little time, those who are near can see that, in each cell, oxygen is gradually accumulating in one tube, and hydrogen in the other. And now I cut off the battery current, and complete the circuit of our four cells. The secondary current at once makes itself manifest, and the deflection of the galvanometer indicates that the direction of the current is contrary to that in which the primary current had previously passed.

Plante's Experiments.—This combination of secondary cells is called Grove's Gas Battery. It has always been an object of great interest to scientific men; but for reasons on which I need not dwell, the current which it produces is extremely feeble, and quite unsuited for practical work. Eighteen years more passed by, and the secondary battery still remained in the obscurity of the scientific laboratory, when, in the year 1860, Monsieur Gaston Planté exhibited his now famous cell before the Acadamy of Sciences in Paris. I think it should always be distinctly recognized that Gaston Planté is the man to whose patient and laborious researches we are mainly indebted for the position which the secondary battery occupies, at the present moment, in the eyes of the world.

These researches were begun in the year 1859, and have been continued, I may say, down to the present day. His first object was to discover what metal was the best fitted for storing up electrical energy in a decomposition cell. After a long series of experiments, in which he tried gold, silver, platinum, copper, and other metals, he finally satisfied himself that lead was the best suited for the object he had in view. In the case of most other metals, the oxygen and hydrogen, produced by the decomposition of water, exist only as little bubbles of gas clinging to the surface of the plates at which they are evolved. But in the case of lead, these gases effect a chemical change, which gives to the plates a new character, of a more of less permanent kind; and this new character constitutes, in effect, the store from which the secondary current is derived.

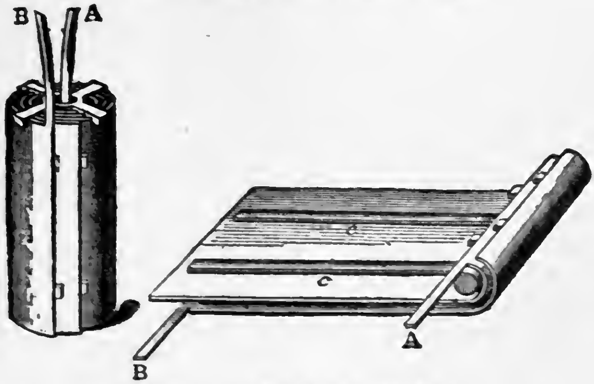
Further, Monsieur Planté discovered that it is possible to increase very much the natural capacity of lead plates for storing electrical energy, by putting them though a process which he called the *formation* of the plates. This process, which extends over a period of three or four months, is much too tedious and complicated to be described in detail on an occasion like the present. But I may say, generally, that it consists in sending a current of electricity through the cell, first in one direction and then in the other, several times in succession, with intervals of rest between; and that the final result is to produce on one plate a substantial layer of lead peroxide, and to reduce the surface of the other plate to the condition of spongy or finely divided metalic lead.

Here are two lead plates, which have been prepared in the manner described; and I will now show you that they contain a store of electrical energy, on which we may draw at pleasure. I plunge them, at a short distance apart, in a glass containing acidulated water; and then I connect them externally by a wire, including, as usual, the galvanometer in the circuit. The index of the galvanometer is immediately deflected to the extreme end of the scale, showing that a strong and steady current is going out from the cell. So long as the two plates retain their distinctive characteristics, so long will the current continue to flow. But, remember, we cannot use our store and keep our store at the same time. As the current continues to flow, oxygen is taken away from the layer of lead peroxide, and deposited on the layer of pure spongy lead; the peculiar character of each plate is thus gradually effaced; the store of energy becomes, in course of time, exhausted; and the current ceases to pass.

The capacity of such a cell as this, for storing electrical energy, increases as the surface of the metal plates is increased. It was, therefore, an object with Monsieur Planté, in the construction of his cell, to have the largest possible surface of lead in a convenient and portable form. To attain this end, he took two plates of lead, about ten inches in breadth, and from twenty to thirty inches in length. These he laid one over the other, separating them by narrow strips of india-rubber; then he rolled them up tightly together in the form of a scroll, and plunged the whole mass endwise into a cylindrical glass jar, containing dilute sulphuric acid. Next followed the process of *formation*, as already described, and the cell was then ready for use. I have here a Planté cell, which, as you see, is about one foot high and four inches in diameter. It was charged a few days ago, and when I now complete the circuit, the current is powerful enough to raise this spiral of platinum wire to incandescence, and produce a brilliant white light.

Faure's Improvement.—The Planté secondary cell has long been used, with advantage, to store electrical energy for small surgical operations; it has been used also, to some extent, for the production of the electric light. But the *formation* of the plates is a process so tedious and costly that this form of cell, on a large scale, is not likely, I think, to come into general use. Hence a lively interest was awakened, last year, when it was announced that Monsieur Faure, of Paris, had invented a new secondary battery, in which there was no need of such a process.

The plan adopted by Monsieur Faure may be explained in a few words. He first covers over the surface of the two lead plates with a thick layer of red oxide of lead; then he immerses them in a cell containing dilute sulphuric acid, and sends an electric current through the cell from plate to plate. The effect of the current is, practically, to deposit oxygen on the plate at which the current passes in, and to abstract it from the plate at which the current passes out; thus raising the layer of red oxide, on the one plate, to the condition of lead



THE LEAD PLATES OF THE PLANTÉ CELL.
On the right, the Plates are seen opened out; on the left, they are seen rolled up.

A B Strips of Lead, one projecting from each Plate. | c c Strips of India-rubber to insulate the Plates.

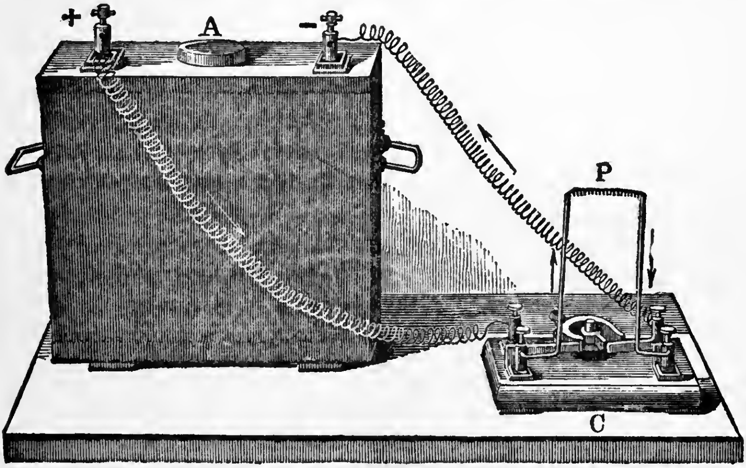
peroxide, and reducing it, on the other, to the state of pure metallic lead. This change is accomplished in one or two days; and when it is complete, the cell has got its charge. It will keep this charge stored up, with very little loss, for a period of several days, or it will give it

THE PLANTÉ CELL COMPLETE.

A Strip of Lead by which the Charging Current enters the Cell. | B Strip of Lead by which the Charging Current leaves the Cell.

out, at our pleasure, whenever it is wanted for use.

In practice Faure uses for his cell a rectangular box, which holds ten or twelve plates. Each plate is covered over tightly with felt to prevent the paste of red oxide from falling off, and the plates are so connected together that they act as two single plates, of very large surface. The amount of electrical energy that can be stored in one of these cells may be expressed in terms of mechanical energy; and it has been determined, by accurate measurement, that a cell, weighing somewhat less than a hundred pounds, can store a million foot pounds of energy, which is equal to one horse-power working for about thirty minutes. Such a cell as this, fully charged, is here on the table before you, and fairly represents the "marvellous box of electricity" which appeared in England, for the first time, last summer, and of which so much has been written and spoken during the past twelve months. The wires coming from the two poles of the cell are connected, as you see, with the binding screws of this commutator; and when I turn the



THE FAURE CELL IN ITS EARLIEST FORM.

A The Cell; A Wooden Box, with a Hole in the Top, closed with a Bung, for introducing the Acid.
C The Commutator.
P Platinum Spiral.

handle of the commutator, a current of electricity flows through a spiral of thick platinum wire, producing intense heat, which makes the wire glow.

What a Storage Battery can do.—You will have no difficulty now, I think, in understanding what a storage battery is, and what it is able to do. It is simply a number of these cells—twenty, thirty, or a hundred—ranged side by side, combining their forces together, and ready, at the turn of a handle, to pour forth a powerful stream of electricity, which we may use at pleasure, either to illuminate our houses or to drive our machinery. A small battery of this kind is set up here on the table beside me. At present the current is not flowing, and the energy of the battery remains stored up. But I now complete the external circuit by turning the handle of this little commutator. In a moment half a dozen incandescent lamps scattered over the table are all aglow, shining with a brilliant white light.

At a little distance, on another table, are four more lamps which are still dark. I turn another handle, and they too begin to glow, while the first continue to shine as brightly as before. On the floor, at my left, is a circular saw, provided with an electro-motor to drive it. I turn a third handle, which brings the electro-motor into the circuit of our battery; the saw is driven rapidly round, and cuts right through a stout piece of timber which my assistant presses against it. By reversing the motion I can, of course, stop the machinery, or put out the lamps, just as I please: or I can shut off the current altogether, and the energy that remains will continue stored up in the battery, until it is again wanted for use.

But some one, perhaps, may be disposed to ask, What, after all, can be the use of a storage battery, if, as I have told you, we can get no electrical energy out of it except what we first put in? Is it not a new element of expense, interposed between the manufacture of an electric current and the consumption of it? I answer, it is useful because it is convenient. It promises to do for electricity what a gasholder does for gas: to store it up according as it is made, and to give it out according as it is wanted. Further, I say it is useful, because it puts it in our power to turn to useful account a vast supply of energy which is now simply going to waste. What the mill-pond does, on a small scale, for the miller, the storage battery promises to do for the whole population, on a scale of great magnitude: to catch the energy of the flowing stream, which is now running idly by, almost at our very doors, and to lay it up, in a convenient form, until we are ready to use it.

Practical Illustrations.—If I have not already trespassed too far on your patience, I should like to touch briefly on one or two illustrations of this interesting and practical question. Suppose you want to light your house with those beautiful incandescent lamps of which I have shown you some specimens here to-day, you have only to get a storage battery, proportioned in size to the illumination you require, and stow it away in a convenient corner of your basement floor. A wire is laid on to your house from a central station, your battery is charged every morning with a store of electrical energy, and you can draw on that store, to illuminate your house, just when you please, and how you please.

I may mention, in passing, that Mr. Edison has just invented a very simple apparatus to measure the amount of current that comes into your house: thus you will only have to pay for what you get. And Sir William Thomson has invented an apparatus which, of itself, will cut off the current as soon as your battery is fully charged: thus you will only get what you want, and none will go to waste. It may be observed, too, that if you desire a more than usually brilliant illumination, for some festive occasion, you have but to order a few extra cells and hire a few extra lamps.

Again, let me take the case of a small country town, with a waterfall near at hand, or a strong flowing stream. The energy of the falling water can be converted into an electric current, at hardly any cost, by means of dynamo-electric machines. Then, if a large storage battery is provided for the illumination of the streets, and if each house has its own small battery for private use, the energy of the stream during the whole period of twenty-four hours can be stored up to light the town during the hours of darkness. A greater store of electrical energy will be wanted, of course, in winter than in summer, as the period of darkness is longer; but Nature happily provides for this increased demand by giving us, in winter, a stronger flow of falling water.

The Storage Battery as a Motive Power.—As a motive power, these storage batteries seem eminently fitted for driving tram-cars. An ordinary tram-car, with its full complement of passengers, weighs about four tons. To drive this weight, at the rate of six miles an hour, we should require an electro-motor working at about three or four horse-power on the level road, but capable of working up to eight or ten horse-power, in going over bridges and up steep inclines. Now, from the experience we already possess, I think I am safe in saying that the electrical energy required to work such a motor continuously, for two hours, can be stored up in boxes that would fit conveniently under the seats of the car. If this be so, then it would only be necessary to provide a large supply of these storage batteries at one end of the line; to set up a couple of steam engines which could be kept constantly at work, charging the batteries; and we might get rid, at once, of a whole troop of horses, with all their attendant expenses.

In the application of storage batteries to the driving of tram-cars, there is one point of especial interest on which I would dwell for a moment. Every one must have observed what a great waste of energy takes place every time a tram-car is stopped on its journey. Moving at the rate of six miles an hour, it possesses, within itself, a very considerable store of energy, and before it can be pulled up all that energy must be destroyed. If it is destroyed by means of a brake, it is simply wasted; if it is destroyed by the aid of the horses, as often happens, then not only is it wasted, but fresh energy is expended in wasting it; and when the tram-car is again started, the horses are called on for a new effort to develop once more the energy which has just been destroyed. Hence it has long been a project with mechanical engineers to devise some means of storing up the energy with which the tram-car is moving before it is stopped, and to use that store for starting it again. Up to the present time this project has been little more than a dream, but it would seem that these storage batteries now enable us to make it a reality.

When the battery is driving the tram-car, a current of electricity flows from the battery into the electro-motor, causing the bobbin of the electro-motor to rotate on its axis, and thus driving round the wheels of the tram-car, which are connected with the bobbin. But it is quite possible, by the mere turn of a handle, so to alter the relation between the electro-motive force of the battery and that of the motor, that this process shall be exactly reversed. The revolving wheels of the tram-car will then drive the bobbin round, thus generating an electric current, which will flow back into the cells, and charge the battery. The moment this change is made, the moving tram-car not only ceases to receive any further impulse from the battery, but it is called upon to do work, in generating an electric current. In doing this work it rapidly expends its store of energy, and soon comes to a standstill. But the energy thus expended is not wasted; it is added to the store of energy already existing in the battery; and when the handle is turned back to its former position, it will help to start the tram-car again.

From tram-cars it is not a very violent transition to private carriages. No doubt, so long as our streets remain in their present condition, we must be content to jog along in the jolting and jarring fashion to which we are accustomed. But if I might fancy a time when our rugged pavement had given way to a smooth and pleasant flooring of asphalte, I see no reason why a box of these cells might not take the place of horses in carriages and other vehicles. On such a roadway one horse power would be amply sufficient to drive a fair-sized carriage, as fast as it would be safe to go through the streets of a crowded city; and a moderate-sized battery, which might be stowed away in a convenient recess of the carriage, could store up energy enough to yield the work of one horse for a drive of two or three hours.

The Storage Battery on its Trial.—And now, in coming to an end, I should wish to remind you of what I said in setting out, that the practical value of this storage battery can be fully determined only by actual trial. At the present moment, it seems to me somewhat in the condition of a hot-house plant; which blooms and flourishes so long as it is confined to the artificial atmosphere in which it has been nurtured, but which, when transferred to the open air of our gardens, is found, very often, unable to bear the rough winds and the changeful climate of a ruder life. This secondary battery has hitherto been carefully and tenderly cherished, under the artificial conditions of the scientific laboratory; and under these conditions it has shown quite a wonderful and vigorous development. The time is now come when it will be called upon to encounter the rough usage and, so to say, the wear and tear of a working life. If, like a hardy plant, it is able to accommodate itself to these new conditions, and continues still to flourish and to develop fresh growth, then there is not one of the speculations I have set forth which may not be realized, even in our own day. But if it should break down under the trial that awaits it, and if our speculations should come to nought, nevertheless the great principles on which I have been insisting—which rest on the solid foundations of science, and which we have found so beautifully illustrated by the secondary battery—these principles will still survive, and the time we have spent in discussing them will not, I trust, have been spent in vain.

On the Recent Progress and Development of the Storage Battery.

Soon after the date of the above Lecture, the storage battery began gradually to come into use, for practical purposes. In many respects it amply fulfilled the hopes awakened by its first discovery. But, as in the case of most other inventions, when it was put to actual trial, some unexpected difficulties presented themselves.

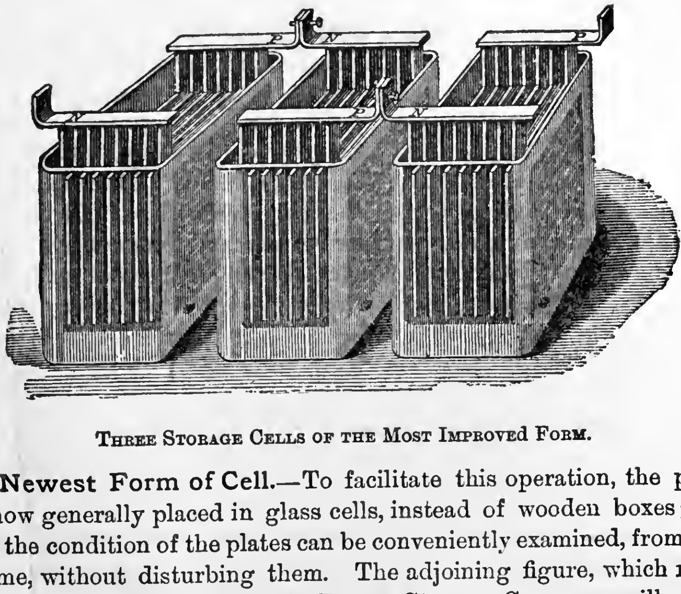
Modifications of the Faure Cell.—In the first place, it was found that, after the Faure Cell had been a little time in use, the current leaked across from one plate to the other, through the flannel, or felt, by which they were separated; and of course the current, in so far as it thus leaked from plate to plate, was practically wasted, and ceased to be available for useful work. To meet this inconvenience, the felt was got rid of, and the plates were kept in position by short studs of ebonite, or india-rubber, fixed between them. An incidental advantage of this change was that the internal resistance of the cell was reduced: a matter of great importance in connection with Electric Lighting.

It became, however, necessary to devise some means by which the paste of lead oxide might be made to adhere firmly to the plates, when deprived of the support which it had previously received from the felt. This has been effected by a new method of preparing the lead plates. Before the paste is put on, every plate is honeycombed on each surface with an immense number of quadrangular indentations, or cells, sinking some distance into the thickness of the plate. The paste of lead oxide is then pressed into these cells, and when it dries it holds a firm grip of the plate, and presents a uniform surface to the action of the acid.

It may be well, perhaps, to say that the plates are now made, not of pure lead, as formerly, but of an alloy, which is harder than lead and stands the work better. The paste, too, which is used to cover the plates is not exactly the same for the two plates of each cell. The positive plate, that is, the plate at which the current enters when the cell is being charged, is covered with a paste of red lead ($Pb_3 O_4$), and the negative plate with a paste of Litharge, or lead monoxide ($Pb O$). In both cases the oxide is largely converted into sulphate of lead, in the process by which it is prepared; and then, in the charging of the cell, the sulphate of lead is changed into peroxide of lead ($Pb O_2$), on the positive plate, and reduced to the condition of spongy lead on the negative plate.

Difficulty of maintaining Insulation of the Plates.—But even this improved form of cell is not without its faults. It is found that the lead peroxide, however firmly it may be set in the first instance, has a tendency to come off in scales, which fall down to the bottom of the cell. Hence if the lead plates rested on the bottom, a conducting layer of peroxide would, sooner or later, be formed between them, and the insulation of the plates thereby destroyed. This danger has been successfully obviated, by not allowing the plates to rest on the bottom of the cell, but supporting them on ridges of ebonite, or glass, or other insulating material.

Sometimes, however, it will happen that the scales of peroxide, in falling down, get caught between the two plates, and thus form a bridge, which practically destroys the insulation of the plates. There is no way yet known of preventing this evil: but it may be remedied, when it arises, by passing a thin lath of wood, or ebonite, or some such material, between the plates, and setting free the scales of peroxide, which will then fall to the bottom.



THREE STORAGE CELLS OF THE MOST IMPROVED FORM.

Newest Form of Cell.—To facilitate this operation, the plates are now generally placed in glass cells, instead of wooden boxes; and thus the condition of the plates can be conveniently examined, from time to time, without disturbing them. The adjoining figure, which represents three cells of the Electric Power Storage Company, will give a good idea of the Storge Cells, in their most improved form. It will be observed that each negative plate, marked N, consists of eight separate plates, joined together, at one end, by a thick strip of lead; and that each positive plate, marked P, consists of seven separate plates, similarly joined. Moreover, the negative plate of one cell is connected with the positive plate of the next: this arrangement is known as "arrangement in series," and is the one most commonly used for practical work.

Buckling of the Plates.—Perhaps the most serious difficulty encounted in the use of Storage Batteries is that, when a cell has been in use for some time, the positive plate shows a tendency to bend, or "buckle," as it is called; and, in this way, it comes into actual contact with the negative plate, thus forming a short circuit through which the cell is discharged. This evil, which is fatal to the usefulness of a cell, is said to be hastened if the Battery is too rapidly charged, or too rapidly discharged, or if the charge is reduced too low, or if the Battery is left too long uncharged. But, even with the greatest care, the evil cannot be altogether prevented; and, after lengthened use, the positive plates will buckle and become useless. How far this fault will eventually interfere with the practical utility of the Storage Battery, it remains for future experience to determine.*

Available Energy of a Cell.—There is one respect in which the anticipations, expressed in my Lecture, have not yet been fully realized by experience. In the early days of Accumulators, it was usual to speak of each cell as containing so many foot-pounds of energy; and it was tacitly assumed that this energy was available in whatever way we might please to use it. Thus, for example, a million foot pounds of energy is equivalent to half a horse-power for an hour; and it was assumed that, if we had two cells, each containing a million foot-pounds of energy, we had practically at our disposal one horse-power for an hour.

But this assumption was soon proved to be inadmissible in practice; First, it was found that we cannot drain off all the energy stored up in a cell, without doing serious injury to the plates. If we wish to keep our Battery in good condition, we must take care only to draw off a certain portion—not more than two-thirds—of the energy it contains. It is usual now to speak of this available portion as the *useful* energy of a cell; and in all practical calculations we should take into account, not the total energy stored up, but only the useful energy.

Again, even as regards the useful energy, we are not at liberty to draw it off at any rate we please. We have learned from experience that, for every storage cell, according to its size, there is a certain maximum rate, at which the energy may be drawn off, in the form of an

*It is right to notice here that the Electric Power Storage Company have, quite recently, brought out a new type of cell, in which, they say, "the plates are so arranged that there is no possibility of internal short circuits caused by the lodgment of plates or pellets of oxide, or powdered paste, at the bottom of the cells;" and for which they further claim that "internal short-circuiting is impossible." If we may accept these statements literally, and if they be verified when the cell has been subjected to a sufficiently long trial, it would seem that the difficulties described in the text have been, at length, completely overcome.

electric current, without injury to the plates; but if this rate is exceeded, the plates will soon begin to buckle. Thus, for example, in a particular form of cell now made, the useful energy stored up is equivalent to one horse-power, for an hour: but we cannot use it *at the rate* of one-horse power, and draw it all off in an hour, without seriously damaging the plates; we can use it at the rate only of one-tenth of a horse-power, drawing it off in ten hours.

These principles, which were not so clearly understood at the date of my Lecture, create some difficulty, no doubt, in the application of storage cells to the driving of tramcars and other vehicles. In the case of a tramcar, for instance, if we want ten horse-power for an hour, to run a double trip of three miles each way, it is not enough to provide cells with that amount of energy stored up; we must take care first, that the amount of *useful* energy stored up is equal to ten horse-power for an hour, and secondly, that it may be drawn off *at the rate* of ten horse-power, without injury to the plates.

But notwithstanding this difficulty, there seems to be little doubt that, in a few years, storage cells will be very generally employed at the motive power on tramway lines. Already, on the Continent of Europe, tramcars are driven by Accumulators in Brussels, in Hamburg, and in Cologne. Even in England, which is rather behind hand, as compared with other countries, in the practical applications of electricity, there are two lines of tramway worked by Accumulators, one in London, and one in Brighton, each about four miles in length.*

Storage Battery for Electric Lighting.—As regards Electric Lighting, the Storage Battery, in its improved form, is now largely used, with great advantage, in the case of small installations. The Battery is placed in the basement story of a house, or in an out-office, and is charged at any convenient time, once or twice, or oftener, in the week, by means of a dynamo, worked by a gas-engine, or a steam-engine, or by water power; and then the lamps may be turned on, at any hour of the night or day, according as they are required. Such a Battery is, no doubt, an expensive element in an Electric Light installation. But it has two great advantages: first, it gives a perfectly steady current, and, therefore, a perfectly steady light; and, secondly, it may be charged at whatever time may be found most convenient, and used whenever it is wanted. I would go so far as to say that, for a small Electric Light installation, especially in a private house, a Storage Battery is not only useful, but practically indispensable.

The case is different, however, when we come to deal with a central station, designed to send out currents for a house-to-house illumination, over a given area. It is sometimes said that great Storage Batteries would be just as necessary, at such a central station, as great gas-holders now are at a central gas station. I am not inclined to take

*See The Electrician, May 25, 1888. page 84.

this view of the question. If it should be found necessary to store the electrical energy generated at a central station, I think it can be stored more economically at the houses of the consumers, than at the central station itself. For this purpose, it would only be necessary that each house should be provided with a Storage Battery, suitable to its wants; and the Battery could be charged by a current from the central station, whenever required.

But it is by no means certain that a Storage Battery will be found, eventually, a necessary element in the distribution of electric currents, from a central station. Several attempts have already been made, with more or less success, to carry out such a distribution, on a small scale; and in these attempts, so far as I know, the Storage Battery has not been employed. The problem of a house-to-house illumination, on a large scale, has only been taken in hand quite recently; and we have yet to learn from practical experience, the only certain guide in such a matter, in what way it can be carried out, at once most efficiently and most economically.

THE END