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NOMOS.

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NOMOS:

AN ATTEMPT TO DEMONSTRATE A CENTRAL PHYSICAL LAW IN NATURE.

"How hardly in the midst of our hurry, and jostled by the cares of life,
Shall a man turn and stop to consider mighty secrets;
With barely hours, and barely powers, to fill up daily duties,
How small the glimpse of knowledge his wondering eye can catch."

PROVERBIAL PHILOSOPHY.

LONDON:
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1856.

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NOMOS:

AN ATTEMPT TO DEMONSTRATE A CENTRAL PHYSICAL LAW IN NATURE.

It needs not the gift of prophecy to perceive that many changes in philosophy must result from that mighty revolution in society which is now in progress. The philosopher no longer lounges in his chair and dreams away his time in happy confidence in his own opinions, but he has been roused by the events which have startled the monarch on the throne and the priest at the altar, and he now doubts where once he dogmatised. He doubts, and he does not yet divine what the end of his doubts will be.

Now the creed of science is questioned in nothing more than in the articles which relate to the philosophy of the laboratory, and in these articles a change is necessary which is great in itself, but greater still in its results. It is no longer possible to believe implicitly in the different agents which have played so prominent a part in this philosophy. What is electricity? It is no single agent: it is a name for many agents in one—heat, light, magnetism, and others. What is magnetism? Nothing apart from electricity. What is artificial light? Like natural light, it goes hand in hand with heat, and it has the same power of working chemical wonders upon the magic screen of the photographic camera. What is heat? It is one of the signs of luminous, and electrical, and chemical action. What is chemical power? A power which bursts into light and heat in flame, and which changes into electricity and magnetism in the galvanic trough. What are the attractive forces which are associated with electricity and magnetism, and which play so important a part in chemical changes? Nothing is known about them, and, after all, they may prove to be only varying aspects of that force of attraction which is supposed to be neither electrical, nor magnetical, nor chemical,—even the force of gravity. Indeed, so intimate and inseparable is the connexion between these agents, that it is more easy to look upon them as *signs of action* than as *agents*.

Nor is this the only change which is necessitated in this part of the creed of science. It is commonly held that electricity and the companion phenomena are not only agents, but *imponderable agents*,—agents, that is to say, which are quite beyond the scope of physical inquiry. This opinion, however, is as groundless as the other; for, on careful inquiry, these so-called agents appear to be signs of a certain definite action in ordinary matter,—an action which is found to be obedient to the ordinary laws of chemistry.

The inquiries which have led to these conclusions have also led to the discovery of certain movements, which are themselves of great importance, and which furnish the interpretation to other movements of greater importance still.

It is evident, in short, that the most fundamental changes are necessary in these subjects; and, so far, the whole burden of evidence appears to point to some general law of which light, heat, electricity, magnetism, chemical power, and some kinds of motion, are only so many effects. So far, the whole burden of evidence appears to point to some central law as underlying these so-called agents.

But if great changes are demanded in these matters, great changes are also demanded in other and still more important departments of philosophy. It is not easy, indeed, to draw a distinct line of demarcation between artificial and natural light; and it is equally difficult to separate the phenomena which are correlative of artificial light, from the phenomena which are correlative of natural light. Out of the laboratory, light, heat, electricity, magnetism, chemical power, and certain kinds of motion, appear to be associated in the same manner as in the laboratory. Light, heat, and chemical power attend upon the force of gravity in the solar ray, and render it difficult to regard this force as an isolated and independent agent; and it is not easy to suppose that magnetism and electricity do not enter into the perfect idea of that law by which the earth is ruled. In a word, there are signs abroad which seem to show that the experience of the laboratory has a far wider scope than was at first apparent.

Here, then, is the prospect of other changes in the creed of science; for if this be so, it is at once apparent that many changes must take place in the mode of interpreting several cosmical phenomena. If the law of the laboratory—if we may use this term to express that central law to which the philosophy of the laboratory appears to point—be a universal law, it is necessary that space should be filled, not merely with imponderable ether, but with actual matter; for, according to the law of the laboratory, light, heat, and their companion phenomena are the effects of a definite change in matter; and if there be ponderable matter in space, there must be a resistance to the motions of the heavenly bodies which is not supposed to exist at present. At first sight, then, it would seem that the law of the laboratory cannot be a universal law. But this is not a necessary conclusion.

Now, unquestionably, the orbital movements of the heavenly bodies may be accounted for by supposing that these bodies were set in motion by a tangential impulse in free space, and then left to the action of the force of gravity. The evidence is unimpeachable. But this is not the only explanation. On the contrary, it may be shown that the heavenly bodies must rotate upon their axes and course onwards in orbits of various eccentricity if they obey the law of the laboratory in a region where they encounter a certain amount of resistance in moving. It may be shown also that these movements must begin as well as continue under these circumstances. And hence it is not unreasonable to suppose that the law of the laboratory *may* be the law which governs the movements of the heavenly bodies.

But be this as it may, it is very certain that the force of gravity is not sufficient of itself to account for every phenomenon in which it is supposed to be the principal or exclusive agent. It does not fully account for the tides, or for the wonderful changes which are exhibited in the form of comets. In order to account for these phenomena, it appears to be necessary to have recourse to another agency—an agency which must operate, but whose operation has never yet been properly considered. This is heat. Nay more, it is also found that the same agency which will account for the tides, and for the changes in the forms of comets, will kindle a fire in the heart of the earth, and keep the land above the waters in such a way that in very truth "the bounds of the sea are fixed by a perpetual decree, so that they cannot be passed;" while at the same time it will do much to elucidate what is dubious in the various versions of the past history of the earth. It is found, indeed, that another power, and one scarcely inferior to that of gravity, must be admitted into the idea of cosmical law; and as this second power enters into the idea of the law of the laboratory, this very fact becomes an argument that the latter law is none other than a partial conception of cosmical law.

Nor have we yet arrived at the limit of the innovations which appear to be required in the creed of science; for, on pursuing the inquiry, the same law is found to lead us to the physical interpretation of natural light and its associate phenomena.

No very satisfactory explanation has yet been offered of natural light. It is, we are told, the sign of an undulation of inconceivable rapidity in an imponderable ether which pervades all space. The imagination is taxed to the utmost to take in the subtle conception. But this difficulty is at an end if the law of the laboratory be invoked to the explanation of the phenomenon, for then the light becomes the necessary effect of the law. The light reveals the presence of the law, and the law explains the nature of the light.

It is so also with natural heat, with the chemical powers of the solar ray, and with the manifold manifestations of terrestrial electricity; and it is not too much to say, that we know nothing about their causes, unless we allow the law of the laboratory to be a universal law. If we do this, then they become only so many signs and effects of the law, and the difficulty is, not to account for their presence, but to imagine their absence.

The law of the laboratory, then, must be regarded as a cosmical law, for the more it is examined into the more it is seen to gain in comprehensiveness, until at length it loses every trace of speciality. This, then, is the great change which appears to be necessary in the creed of science; and that this change is necessary, and that it will lead to the results which have been specified, is what we propose to show in the following pages.

CHAPTER I.

SEARCH AFTER A CENTRAL LAW IN THE PHENOMENA OF ARTIFICIAL FORCE.

The connexion between artificial electricity, light, heat, and other agents indicating the existence of some hidden central law.

THE researches of late years have shown that the artificial manifestations of electricity, light, heat, and many other agents, are connected in a very intimate manner; and the question of the present day is, not whether they are thus connected, but whether we are to agree with Mr. Grove in regarding them as reciprocally transmutable. Or rather the question is, whether these so-called agents are agents at all, for on further inquiry it is found to be more easy to look upon them as *signs of action* than as *agents.* Everything, indeed, seems to point to a connexion which cannot be severed, and which renders it impossible to detect the real law of any one agent without at the same time discovering the real laws of the companion agents; in other words, everything seems to point to some undiscovered central law of which electricity, light, heat, and the associate phenomena, are only so many effects. Is there, then, such a law? This is the great question which we here propose for solution, and which we will endeavour to solve by analysing, first of all, the phenomena of electricity. We will do this because in these phenomena we find the way which appears to lead most directly to the desired result.

What, then, is electricity? There are, we answer, several kinds of electricity. There is ordinary electricity, or that which is obtained from the common machine, from the atmosphere, and from several other sources; there is voltaic electricity, or that which is yielded by the common pile or battery; and besides these, which are the principal kinds, there are the electricities which are elicited from magnetism, from heat, and from animals such as the torpedo. All these several kinds, however, are allowed to be essentially one and the same. This is allowed; but it is necessary for our purpose to state the evidence upon which this identity is established, even though this evidence be long and in some respects tedious. At the same time we may assume the identity of the electricities which are derived from magnetism, from heat, and from animals such as the torpedo, and at once proceed to show the identity of ordinary and voltaic electricity. We may do this because the two latter kinds of electricity are incomparably more important than the others, and because the identity of the others with themselves and with these is proved by a similar train of arguments. We proceed then, first, to consider the identity of ordinary and voltaic electricity—a question of great interest and importance, and one which affords the clue to almost all the questions which remain in the background.

Search after the hidden central law in the phenomena of artificial electricity.

Identity of voltaic and ordinary electricity.

In considering this identity, we will take the evolution of heat, the magnetism, the chemical action, the shock, and the spark—all of which are familiar phenomena of voltaic electricity—as preliminary points of comparison.

It is well known that ordinary electricity agrees with voltaic electricity in the evolution of heat, and that a wire may be fused by either kind indifferently, provided the quantity be sufficient.

Ordinary electricity agrees with voltaic electricity in the power of magnetising iron or steel, and the direction of the magnetic current thus induced holds the same constant relation to the electrical current in either case; but ordinary electricity has not the same power of *deflecting* the magnetic needle as voltaic electricity. M. Colladon, of Geneva, however, was led to suppose that this difference might be owing to the use of very insufficient quantities of ordinary electricity; and, on remedying this deficiency, he procured the wanting deflection. Nor need it be any matter of surprise that deflection should be wanting under ordinary circumstances, for the very shock of the discharge is sufficient to derange, diminish, or even invert, the magnetic power of the needle. And this is the great reason why the deflection was so long wanting, for Dr. Faraday has shown that the needle is deflected even by *small* quantities of ordinary electricity, if a sufficiently delicate needle be used, and if the shock be diminished and the discharge retarded by causing the current to pass through wet thread or through some other bad conductor. He has also shown that the needle moved to this side or that as the direction of the current changed, and always in obedience to the law which rules the movements of the needle under voltaic electricity.

Ordinary electricity agrees with voltaic electricity in being attended by the same signs of chemical action. This has been proved by Dr. Wollaston, and more conclusively still by Dr. Faraday. The latter philosopher obtained his proof by passing ordinary electricity through small pieces of paper soaked in certain chemical solutions, the current being first bridled by making it pass in some part of its course through a piece of wet thread. When solution of sulphate of soda was used, the acid was evolved at the places where the current entered and the alkali where it left, and this equally in each piece of paper when several pieces were arranged in a row. The experiment is as follows:—"Three compound pieces of litmus and turmeric paper were moistened in a solution of sulphate of soda, and arranged on a plate of glass, with platinum wires, as in the figure. The wire *m* is connected with the

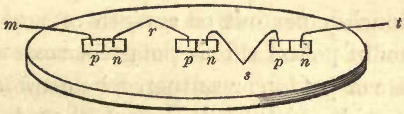


Fig. 1.

prime conductor of the machine, the wire *t* with the discharging train, and the wires *r* and *s* enter into the course of the electrical current by means of the pieces of moistened paper; they are so bent as to rest each on three points, *nrp*, *nsp*, the points *r* and *s* being supported by the glass, and the others by the pieces of paper; the three terminations *ppp* rest on the litmus, and the other three *nnn* on the turmeric paper. On working the machine for a short time only, acid was evolved at the poles or terminations *ppp* by which the electricity entered the solution, and alkali at the other poles *nnn*, by which the electricity left the solution."* If the direction of the current be reversed in this experiment, the alkali and acid immediately change places. Now in this, and in all experiments intended to elucidate this point, an important source of error must be guarded against. The electricity must be made to pass *through* the paper, for if it be allowed to pass *over* it as a spark, some nitric acid is formed by the combination of the nitrogen and oxygen of the atmosphere; and this acid will redden the litmus paper, and prevent the appearance of the brown alkaline stain upon the turmeric paper. This was first pointed out by Cavendish. Such, indeed, is the extent to which nitric acid may be formed under these circumstances, that Dr. Faraday was soon able to form touch-paper out of a piece of paper soaked in solution of potass. This potass became converted into nitrate of potass, or saltpetre, by combining with the nitric acid, and thus the paper when dry became touch-paper.

It is said that ordinary electricity, like voltaic electricity, has the power of decomposing water; but this is not proved by the experiments which are

* "Experimental Researches in Electricity," vol. i. p. 90.

usually cited for the purpose. The quantity of ordinary electricity, as will be shown presently, is altogether insufficient to produce any marked results. Gases are certainly evolved from the water, but their quantity is too small to allow us to speculate upon their nature — so small that Dr. Faraday "could not obtain at either pole a bubble of gas larger than a small grain of sand," after working a large machine for half an hour. We shall revert to this point again; but in the meantime sufficient has been said to show that voltaic and ordinary electricity agree in having, though in unequal degrees, the same definite power of chemical decomposition.

Ordinary electricity agrees with voltaic electricity in being attended by the same shock when a strong current is passed through the body, and the results are not dissimilar when weaker currents are experimented upon. "When," writes Dr. Faraday, "a wet thread is interposed in the course of the current of ordinary electricity from a battery charged by eight or ten revolutions of a machine in good working order, and the discharge is made by platina spatulas through the tongue or gums, the effect upon the tongue and eyes is exactly that of a momentary feeble voltaic current."

Ordinary electricity agrees with voltaic electricity in having light as one of the signs of the discharge. The light of ordinary electricity is distinguished by its instantaneousness, and by being accompanied with a sharp explosive noise; but if the discharge be retarded by passing it through some wet string away from the place where the spark has to pass, the light is less instantaneous, and it is accompanied by little or no noise. It approximates under these circumstances to the character of a voltaic spark. It is also to be observed that there is no visible difference between the two kinds of spark when they are taken between amalgamated surfaces of metal, at intervals only, and through the same distance of air.

It appears, therefore, that ordinary electricity agrees with voltaic electricity in the points which we have taken as preliminary points of comparison, —the evolution of heat, the magnetism, the chemical action, the shock, and the spark, — and so far their identity may be allowed. But this is not the only evidence in favour of this identity; and thus, on continuing the inquiry, we find that in both cases there are similar attractions and repulsions (?) before the circuit is complete, and that the actual circumstances of the discharge may be assimilated in a great degree.

The familiar attractions and repulsions (?) which are displayed by the common electrometer are very characteristic of common ordinary electricity. They are very marked, even at considerable distances. Now, there are similar attractions and repulsions (?) in the case of voltaic electricity; and the only difference is, that they are less marked, and that they do not happen at such great distances. They are, however, very unmistakeable. Thus, the gold leaves of the electrometer will diverge when the instrument is placed in connexion with either end of a galvanic battery, or even when brought within half an inch of the end; and they will again collapse if, after having thus diverged, the instrument be carried to the other end. Why there should be any difference, even in degree, will appear presently.

In the circumstances of the discharge there appears to be a very great difference between the two electricities. Ordinary electricity, as everybody knows, may be discharged at a considerable distance through the air. It is enough to bring the knuckle within the neighbourhood of the charged conductor to receive the spark and shock. With voltaic electricity, on the contrary, actual contact is necessary to the discharge; and it is generally necessary to moisten the hands which grasp the conductor before the shock can be felt. The discharge of ordinary electricity, however, is greatly facilitated under certain circumstances, as by making the current pass through heated air, or through a vacuum; and Dr. Faraday has also shown that the discharge of voltaic electricity is facilitated under the same circumstances. He has shown that voltaic electricity may be discharged at a considerable distance across the exhausted receiver of an air-pump, or when the poles and the intervening space are heated by a spirit lamp, and that the discharge was interrupted when air was re-admitted into the receiver, or when the heat was removed. Voltaic electricity may also be discharged at some distance when the poles are first joined for some time and then separated. Under these circumstances the poles and the surrounding air become heated by the current while the poles remain together, and this heat acts like the heat of the spirit lamp after the poles are separated. The explanation is the same.

What then? If there is no real difference between ordinary and voltaic electricity in any of these respects, where is the difference, for difference there assuredly is somewhere? Now the only difference which can be found is in simple quantity, and this is astonishingly great.

Dr. Faraday's solution of this question, as of every other question which he has undertaken to solve, is most conclusive. In this solution the first thing to be determined was whether the same absolute quantity of ordinary electricity sent through a galvanometer under different circumstances will cause the same deflection of the needle. This was found to be the case; for, on turning the machine a certain number of times, the needle was always deflected to the same point, whether the charge was collected in one Leyden jar or in several, and whatever the retarding power of the medium through which the discharge was effected. This point being determined, the next step was to compare ordinary and voltaic electricity, quantity by quantity, by means of the deflection of the needle.

Apparent difference between voltaic and ordinary electricity a difference of quantity, and not of kind.

In this comparison the machine used had two sets of rubbers, and its plate was fifty inches in diameter. The prime conductor consisted of two brass cylinders connected by a third, the whole length being 12 feet, and the entire surface in contact with the air about 1422 square inches. When in good working order, each revolution of the plate gave 10 or 12 sparks from the conductor, each an inch in length; and sparks of 10 or 14 inches in length could be easily obtained. The electric battery used consisted of 15 jars, each 23 inches in circumference, and each having about 130 square inches of coating. The galvanometer was one of ordinary sensitiveness, having an arbitrary scale, of which each division was equal to about 4°. The discharging train was a thick wire, the further extremity of which was connected with the gas and water pipes belonging to the house. The experiment was to charge the battery by *thirty* turns of the machine, and then, having included a thick wet string about ten inches in length in the circuit, to discharge the battery through the galvanometer, and notice the deflection of the needle. The result was, that the needle immediately became deflected through five and a half divisions of the arbitrary scale. This is the first fact in the comparison.

The next thing was to ascertain how much voltaic electricity was required to produce this amount of deflection; and now the difficulty was to get a voltaic apparatus of sufficient minuteness. After many trials, however, Dr. Faraday succeeded in finding that the same degree of deflection was caused by two mere wires, one of platinum and the other of zinc, $\frac{5}{8}$ths of an inch in length, $\frac{1}{18}$th of an inch in diameter, and $\frac{5}{16}$ths of an inch apart, when immersed in four ounces of water acidulated with one drop of ordinary sulphuric acid (a dilution of which the acid could neither be tasted or tested with any distinctness) for three seconds.

Taking the power of decomposition as the measure of quantity, Dr. Faraday also found that iodide of potassium was decomposed, and the same amount of iodine set free by this infinitesimal battery in three seconds as by thirty turns of the large machine.

Now it is extremely difficult to realize the extent of this amazing difference in quantity. The amount produced by thirty turns of the machine, if passed through the head of a cat, is enough to cause instantaneous death; and what then must be the amount produced by an ordinary voltaic battery, if the merest fragments of wire can give out in an instant so great an amount! Dr. Faraday calculates that the amount produced by the battery in the time required to decompose a single grain of water, will be at least 800,000 times as much as that produced by thirty turns of the machine—an amount which, if measured at all, can only be measured by all the lightnings of a terrific thunderstorm. Although difficult to realize, however, this difference in the quantity of the two electricities is perfectly real, and if other proof is necessary, it may be found in the common Leyden jar. This jar may be charged indifferently by either electricity, and the signs of charge and discharge in either case are perfectly indistinguishable. The only difference is, that the action of charging by the electrical machine is a matter of time and labour, whereas the act of charging by the voltaic battery is the work of an instant. A mere touch with the poles is enough to charge to the utmost. Now this is as we might expect, if, as is certainly the case, a certain quantity is necessary to the charge, and, being so, the jar not only shows the amazing difference in quantity between ordinary and voltaic electricity, but it becomes, as it were, a kind of neutral ground upon which the two electricities are able to meet and display their common properties.

With this amazing difference in quantity, then, we need be at no loss to account for any apparent differences in the phenomena of ordinary and voltaic electricity which have not yet been accounted for. We can understand, for instance, how so little water should be decomposed by ordinary electricity, as compared with voltaic electricity, if it requires 800,000 times the quantity which is produced by thirty turns of a large machine to decompose a single grain; and if the deflection of the magnetic needle bears any proportion to the quantity of electricity acting upon it, it follows that it must be infinitely more difficult to cause any deflection by ordinary than by voltaic electricity. These difficulties, in fact, cease to be difficulties, and this will appear more distinctly in the sequel; but we may leave them now, for sufficient has been said to allow us to infer the identity of voltaic and ordinary electricity.

The other kinds of electricity are found to possess no characteristic features, and they agree with voltaic and ordinary electricity in every essential particular. All this is proved by a similar train of arguments to that which has just been used; and as the proof is not at

Identity of other kinds of electricity with ordinary and voltaic electricity.

all questioned, we will therefore assume that all kinds of electricity are really identical, and proceed once more to ask—what is electricity?

Before proceeding to put this question, however, it may be well to arrive at some clear conception as to the meaning of some terms in common use, such as conduction and insulation, charge and discharge, current and tension; for this, we shall find, will materially facilitate our future inquiries.

Electrically, bodies are divided into two classes—conductors, and non-conductors or insulators; and this division may be illustrated by the working of the common electrical machine. The metallic parts are conductors; the glass parts and the surrounding air are non-conductors. On turning the handle, electricity is developed in the plate or cylinder by friction against the rubber, and this electricity is communicated to, or "induced" in, the conductor. There the electricity is *conducted* into every part of the "conductor," for, as its name implies, this part of the machine belongs to the class of conductors. The "conductor," however, rests upon a glass foot, and is surrounded by air; and as glass and air belong to the class of non-conductors, the electricity is not *conducted* beyond the limits of the "conductor." The "conductor" is *insulated* by the non-conducting glass and air; and because it is insulated, the electricity cannot be conducted away; and, not being conducted away, the conductor is said to be *charged*. If there was no insulation, the elec-

The analogies of the states called *conduction* and *insulation*, *charge* and *discharge*, *current* and *tension*.

tricity would be conducted from the "conductor" as fast as it was communicated to it, and there could be no charge. It is the same also with the charging of the Leyden jar; only here we are able to seize another link in the process. On connecting the interior of the jar with the "conductor" of the machine, the electricity is *conducted* by the chain to the metallic lining of the jar, because "conductor," chain, and lining are all conductors and all continuous. In this way the jar is *charged*. It is charged because the lining is *insulated* by the glass walls of the jar, just as the "conductor" is insulated by its glass foot and the surrounding air. But the electricity is not confined within the jar. On the contrary, it has got into the coating of the jar, and there is as much in the coating as in the lining. It has got from the lining into the coating through the glass, but not by conduction, for glass is a non-conductor. The process by which it has got through is called, not conduction, but *induction*. Nor is this all. The jar, we find, could not be charged if it were insulated. On the contrary, it must be in connexion with the earth; and so also must be the rubber, from which the electricity is evolved by the revolving plate or cylinder. In other words, there must be no insulating media between the outside of the jar and the rubber. In order to the charging of the jar, indeed, the electricity must be able to act in a *circle*, or from the rubber to the revolving plate or cylinder, from this to the prime "conductor," from this along the chain to the lining of the jar, thence through the glass to the coating, and so back again along the earth to the point from which we started — the rubber. On further inquiry we find, also, that the action which is exercised by the lining of the jar upon the coating is exercised by the "conductor" upon bodies at a distance, as upon the walls of the room in which the machine is worked, and that in this case the intervening air performs the same insulating office as the glass. In short, *induction* is the term which is used to express the passage of electricity across non-conductors, and *conduction* is the term for expressing the same passage through conductors. In other words, *conduction* is an action between contiguous particles; *induction*, an action at a distance.

If now we continue to work the machine, we find that there is a limit beyond which the Leyden jar cannot be charged. Beyond this limit we get *discharge*; that is to say, the electricity in the lining of the jar combines with the electricity in the coating of the jar, and both disappear with the production of light, heat, magnetism, and certain chemical phenomena. Or the same discharge may be produced by connecting the lining and coating of the jar by some conductor, when the discharge takes place principally by conduction. In either case, the electricity is said to travel round the circle, and this travelling is spoken of as a *current*. Before discharge there is no current, and what the actual state is it is not easy to understand. It is generally spoken of, however, as a state of *tension*. It is apparently the electro-tonic state of Dr. Faraday.

In galvanism the electricity is generated, not by the revolution of a plate or cylinder against a rubber, but by the chemical reactions which take place between the metals of the cells and the liquids with which these cells are charged. When the two extremities of the battery are in connexion, the electricity is *conducted* from the zinc of the first cell through the fluid to the copper of the same cell, from the copper along the intervening metallic bridge to the zinc of the second cell, then to the copper, and so on from zinc to copper, cell after cell, to the copper of the last cell, and thence back again through the connecting wires to the zinc of the first cell. The electricity is conducted from beginning to end. There is a free *current*. But if the wires connecting the two extremities of the battery are separated, other phenomena are superadded. If the ends of the wires are kept in close proximity, the current continues to pass, and a vivid spark appears between them. The current, in fact, is formed partly by *conduction* and partly by *discharge*. But if the ends are separated a little more, the spark ceases, and with it the current; the intervening air has become an insulator, and the electricity passes from the state of *current* to that of *tension*.

What, then, is conduction? What is insulation? What is charge and discharge? What are the states of current and tension? It is still Dr. Faraday who supplies the answer; and this answer is, that there is no real and substantial difference between the states of which these terms are the names.

It seems strange that the *insulating* action of the glass of the Leyden jar and the *conducting* powers of the discharging rod should be in any way connected; but so it is. This is seen in many ways. Water, for example, is a conductor; ice is an insulator. If a plate of ice be coated on both sides with tinfoil, and one coating be connected with an electrical machine and the other with the earth, it may be charged like the Leyden jar, and the charge remains so long as the ice continues to insulate the two coatings; but as the ice melts away the insulation fails, and as it fails the electricities in the two coatings unite, not by discharge, but by conduction, for the water into which the ice melts is a conductor. As the ice melts away, the distinctions between conduction, discharge, and insulation seem to melt away also. The non-conducting properties of ice and the conducting properties of water are also paralleled in other substances. Solid sulphuret of silver is an insulator; fused sulphuret of silver is a conductor. Solid fluoride of lead is an insulator; fused fluoride of lead is a conductor. And so also with several other substances. Insulation, moreover, is never absolutely perfect; and for this reason a charged Leyden jar speedily becomes uncharged when left to itself. How is this? Is it that insulation is only *slow* conduction? Again, conduction, even in the best conductors, is not instantaneous: time is required. Is, therefore, the difference between conduction and insulation a mere difference of time? That conduction is not instantaneous is seen in a beautiful experiment of Mr. Wheatstone's, in which a Leyden battery is discharged through a copper wire half a mile in length and divided in the middle, and the time is noted when the spark appears at the ends of the wire and at the division. In this experiment the wire is bent in such a way that all the sparks are placed in the same field of vision. And what is the result? The result is, that the spark at the middle is sensibly behind the sparks at the ends of the wire (which are simultaneous); and, being behind, it is evident that the electricity has not been conducted from the ends to the middle of the wire without a sensible loss of time. The conduction has not been instantaneous.

"If now," as Dr. Faraday reasons, "we leave the arrangement at the middle and two ends of the long copper wire unaltered, and, removing the two intervening portions, replace them by wires of iron or platina, there will be a much longer interval between the appearance of the middle spark and the terminal sparks. If, removing the iron, we were to substitute for it only 5 or 6 feet of water of the same diameter as the metal, we should have still greater retardation. If from water we passed to spermaceti, either directly or by gradual steps through other bodies (even though we might vastly enlarge the bulk, for the purpose of avoiding the occurrence of a spark elsewhere than at the three proper intervals), we should have still greater retardation, until at last we might arrive, by degrees so small as to be inseparable from each other, at actual and permanent insulation. What, then, is to separate the principle of these two extremes, perfect insulation and perfect conduction, from each other, since the moment we leave in the smallest degree perfection at either extremity, we involve the element of perfection at the other end? — especially, too, as we have not in nature the case of perfection, either at one extremity or the other, either of insulation or conduction." *

Conduction, moreover, is intimately connected with the spark, and not with this mode of discharge only; but we will only now speak of the spark. This luminous phenomenon, then, is not confined to the air; on the contrary, it may be obtained in oil of turpentine, in olive oil, in resin, in glass. A metal wire will also ignite when it is not large enough to transmit the electric current; and what is to separate this luminous condition from the ordinary electric spark? Is it not directly allied to the spark by the luminous discharges which occur in glass, in resin, in oil, and in turpentine? And if so, where does the process of conduction end? There is, indeed, no end; and we may say indifferently that the luminosity of the wire is owing to *discharge* between the several component molecules, or that the ordinary spark is the consequence of *conduction* between the aërial particles. Discharge and conduction, indeed, go hand in hand in a beautiful experiment by Sir T. Snow Harris. A fine platinum wire is stretched across a glass globe containing highly rarified air, and a current of electricity is passed through the wire, when the wire and the rarified air surrounding it both become luminous. The wire is not sufficient to carry the current, and part of the duty devolves upon the air; the one

* Op. cit. p. 421.

carrying it by conduction, the other by discharge. More even appears to be carried by the air than by the wire; and we may speak, if we will, of the insulating air as being a better conductor than the conducting wire, under these circumstances.

In a word, conduction and insulation are but extremes of the same process. The idea of current is involved in both,—a quick current in the one case, a slow current in the other. In ordinary conductors, such as metal, the current travels instantaneously; but if these conductors be hemmed around by insulating substances, such as glass or air, time is required for the completion of the journey, and this time is the *period of the charge.* *Charge* is the current thus hemmed in, and travelling very slowly; and *tension* is only another name for the same thing. *Discharge* and *conduction* are practically one and the same. All differences, indeed, are differences of word, and not of fact; and thus we find identity in some of the different modes of electrical action, as well as identity in the different kinds of electricity; and finding this, we are now the better able to proceed with our inquiry, and ask what is electricity?

The connexion between chemical and electrical action.

What is electricity? The first clue to the interpretation of this mystery is found in the arguments which show the identity of ordinary and voltaic electricity; for the direct consequence of this identification is to connect electrical with chemical action. This idea is naturally suggested by the phenomena of the voltaic battery. It was first enunciated by Sir Humphry Davy in a Bakerian Lecture in 1806, and again in 1826, when he stated "that chemical and electrical attraction were produced by the same cause, acting in the one case on particles, in the other on masses, of matter; and that the same property, under different modifications, was the cause of all the phenomena exhibited by different voltaic combinations."* In this, however, as in almost every other question connected with electricity, it required a Faraday to give us definite information.

There is no manner of doubt that the energy of voltaic electricity is proportionate to the energy of the chemical action in the cells of the battery. When these cells are charged with brine, the action is stronger than when they are charged with water; and when they are charged with sulphuric acid, it is stronger still: that is to say, the powers of decomposition, the deflecting influence upon the magnetic needle, and the vividness of the spark, are all directly related to the activity of the chemical changes in the cells of the battery. All this is allowed.

Now the changes in the cells of the battery, so far as we can ascertain, are purely chemical. Under ordinary circumstances, for example, the zinc plate is oxidised at the expense of the water in the cell, and the zinc and water are decomposed in equivalent proportions. In one of Dr. Faraday's experiments, 8·45 grains of zinc were oxidised and dissolved, and

* "Philosophical Transactions," 1826, p. 389.

the quantity of hydrogen evolved from the decomposed water whose oxygen had gone to the zinc (the temperature being 52°, and the barometer 29·2 inches) amounted to 12·5 cubic inches. This quantity, corrected for temperature, pressure, and moisture, is equal to 12·15453 cubic inches of dry hydrogen at the mean temperature and pressure. This quantity, increased by one-half for the oxygen which went to make up the water decomposed, and which has entered into combination with the zinc, gives 18·232 cubic inches of hydrogen and oxygen; and therefore the amount of water decomposed is equal to 2·3535544 grains. Now this quantity of water is to 8·45, the quantity of zinc oxidised, as 9 is to 32·31; so, taking 9 as the equivalent of water, 32·5 becomes the equivalent of zinc: in other words, the decomposition is according to the numbers of chemical equivalents. It is the same, also, with the decomposition of all other compounds; but this illustration must suffice.

There is, moreover, the same definite chemical action at every point of the fluid parts of the circuit, and the same degree of action; and without the action there is no current. If the platinum poles or *electrodes* of the battery be immersed in a glass containing water, some water is decomposed; and if the hydrogen and oxygen into which the water is decomposed be collected, they are found to be in exact chemical equivalents. The amount of decomposition, moreover, is exactly equal to that which takes place in every cell of the battery, as

The connexion between chemical and electrical action in the fluid parts of the circuit.

may be readily seen by measuring the quantity of hydrogen given off. The amount is less, however, than when the electrodes are in simple metallic contact. If now we add a second glass containing water, and remove one of the electrodes out of the first glass into it, connecting the two glasses by a piece of platinum wire, water is decomposed in both glasses, and in the acting cells; and the same quantity is decomposed in glasses and cells, but the amount is less than when only one glass was used. If we add a third glass containing water, and remove the electrode into it, completing the connexion with the next glass by another piece of platinum wire, there is still decomposition in all the glasses, and in all the cells; and the amount is the same in glasses and cells, but it is now very small. If a fourth glass be added, and included in the circuit in the same manner, there is now no decomposition in any part of the circuit. If the action of the battery is weak, the current may be stopped at the first glass; if it is stronger, it may be able to pass through other glasses: but there is always a limit, and the action fails progressively and equally in cell and glass, as glass after glass is added, until the limit is attained. Now this fact is of extreme importance in elucidating the condition of the fluid parts of the circuit. It shows, indeed, that there is the same definite chemical action everywhere, for not only are the oxygen and hydrogen given off in equivalent proportions and in equal quantities everywhere, but they are always given off in relation to the same electrode. It shows, also, that the chemical character of the electrode has nothing to do with this result, for so far as the oxygen is concerned (and the oxygen may illustrate the general fact) the amount is absolutely the same when it is given off in the cell of the battery, and combines with the zinc of that cell, or whether it is given off in the glass in which the platinum electrode is plunged, and with which electrode it cannot combine. The experiment shows, moreover, not only that the electricity originates in the chemical changes within the cells of the battery, but that the current itself is attended by these changes whenever the current has to pass through a fluid. It even seems to hint that chemical changes may be as necessary to the *conduction* as to the *origination* of the current.

But what of the other parts of the circuit? What is the condition of the metals which form part of the circuit? In what state is the air when the current passes through it? Are these the seat of any definite changes such as are found in the fluids?

The connexion between chemical and electrical action in the metallic parts of the circuit.

The condition of the *metallic* parts of the circuit is one of great obscurity; but, thanks to the present illustrious Master of the Mint, the obscurity is not altogether without light. Now Prof. Graham holds "that the ultimate atoms of a metallic mass are under the influence of chemical affinities, being in a state of chemical combination one with another, and not isolated and independent of one another, like loose grains of sand." He believes that metals are composed of *molecules*, or groups of *three* atoms, either two of which three atoms may combine to form an *element* whose properties, as compared with those of the unattached atom, which forms the other *element*, are those of an alkali as compared with an acid. He believes, also, that these two opposite *elements* do actually combine, as an acid with an alkali, to form a salt. According to this theory, then, it is possible to suppose that a metal may be the subject of continual decompositions within itself during the passage of a current, and yet to all outward appearances be never otherwise than the same simple metal. Nor is this theory without foundation; on the contrary, it is firmly grounded on a fact which cannot well be misconstrued, and which will acquire additional significance hereafter. This is the composition of that strange compound, the magnetic oxide of iron. This is a mixed oxide, consisting of one equivalent of protoxide and one equivalent of peroxide; the first consisting of one equivalent of iron and one equivalent of oxygen, the second of two equivalents of iron and three equivalents of oxygen. Neither the protoxide nor the peroxide is magnetic, but this mixed oxide is magnetic. There is also a magnetic sulphuret of iron, whose composition is analogous to this mixed oxide; and similar mixed oxides belong to the magnetic metals, manganese and cobalt. Salts of this character are peculiar to the magnetic metals; and such being the case, it was quite natural for Prof. Graham to consider this peculiar molecular condition as essentially connected with magnetism, and that the condition was essentially chemical in its character; though it is not possible to understand the full logical connexions of these ideas without at the same time understanding the extremely philosophical views of this great chemist upon the constitution of all salts. It was also natural for Dr. Graham to conclude that chemical action was essential to the presence of electricity in a metal, because electricity and magnetism are inseparably united; and being so, the conclusion is, not that a metal *may* be the seat of chemical changes during the presence of electricity in it, but that it *must* be.

The cogency of this reasoning depends, of course, upon the existence of these intimate relations between electricity and magnetism. The evidence is only indirect, and it cannot be otherwise at present. Still, enough has been said to allow us to assume, with some show of reason, that the metallic parts of the circuit, like the fluid parts, *may* be the seat of chemical changes during the presence of the current.

The connection between chemical and electrical action in the aërial parts of the circuit.

When *air* enters into the circuit there is also some reason for believing that it is the seat of definite chemical changes during the passage of the current. We might argue as much from the photographic powers of the electric spark, though these powers are only manifested collaterally, and out of the immediate track of the current. The fact, however, that the discharge is thus marked by chemical functions is an argument that during the discharge the air is the scene of active chemical changes. Of itself, perhaps, the fact would be of little moment, but coupled with what we know of the condition of the fluid parts of the circuit, and with what we may suppose concerning the metallic parts, it acquires both signification and weight. We may also arrive at the same conclusion from the formation of ozone and nitric acid in the aërial track of the circuit, for these substances could not be formed without marked chemical action.

In all parts of the circuit, then — fluid, metallic, and aërial — there are more or less evident traces of chemical action, and so far the connection between electricity and chemical action is strengthened. But many difficulties remain to be solved before we can arrive at any conclusion on the subject, and one of these is to be found in the theory of that state which has been so repeatedly mentioned — *the current.*

What, then, is the current? It has long been the fashion to ascribe the phenomena of electricity to certain attractive and repellent movements in an imponderable agent or agents, and the term current has been used to describe these movements; but the researches of Dr. Faraday and others have gone far to explode these opinions by showing that there are certain definite movements of *matter* during electrical action — movements resulting from a certain state called *polarity.* It is not easy to define this term, but it is one borrowed from the phenomena of magnetism. The idea involved in it is that the opposite sides of atoms acquire opposite properties during electrical action, identical with those which belong to the two ends of a magnet. These sides are in short poles, and hence the term *polarity*. Like poles, these opposite sides attract and repel (?), like sides repelling (?), and unlike sides attracting. When this state of polarity is induced in any one atom, a similar state is induced in the next, and so on indefinitely from atom to atom. And the current is this state of continuous action. Still the term current conveys no very definite idea. During its continuance the polarity is being continually lost and restored — lost by the combination of opposite polarities, restored by their re-formation. It is not onward movement in the ordinary sense of the word. It is, apparently, oscillation. In the words of Dr. Faraday, it is "an axis of power having contrary forces, exactly equal in amount, in contrary directions." There is, however, good reason to agree with Dr. Graham in believing that the current is a sufficiently simple fact, and that it is nothing more than the transmission of certain definite chemical changes in a given direction; and this we now propose to show.

The current a chemical idea.

Let it be supposed that all parts of the circuit — metal, fluid, and air too, if air be included — have dual or polar molecules, and that the two elements of which these molecules consist are endowed with opposite properties, opposite in the same sense that an acid and alkali are opposite. Using the terms in a chemical sense, let us call one of these elements the *positive element*, and the other the *negative element*. Let it be supposed that these elements may be composed of the same or of different substances. Thus, the positive and negative elements of zinc, platinum, and copper, are both composed of zinc, platinum, and copper,—two atoms (perhaps) going to form the positive element, and a single atom (perhaps) going to form the negative element; but the elements of a molecule of hydrochloric acid are of different substances, the positive element being chlorine, the negative hydrogen. Let it also be supposed that new molecules may be formed by the combination of various positive and negative elements, and there appears to be no great difficulty in reducing all the phenomena of the galvanic circuit to the chemical hypothesis.

That this is the case we will endeavour to show in the following series of diagrams. In this series we will indicate the different parts of the galvanic circuit by their respective chemical symbols — the zinc plate by Z*n*, the platinum plate by P*t*, the copper connecting wire by C*u*, and the hydrochloric acid with which the cell is charged by HC*l*. We will suppose, moreover, that each of these parts consists of two molecules, each consisting of its two elements. The two elements of the zinc, platinum, and copper molecules are composed of the same substance, and we will therefore represent these molecules by doubling the symbols, and placing an accent over that which is to represent the positive element. The two elements of the hydrochloric acid molecules are composed of different substances, the hydrogen, H, being the negative, and the chlorine, C*l*′, the positive. Thus: —

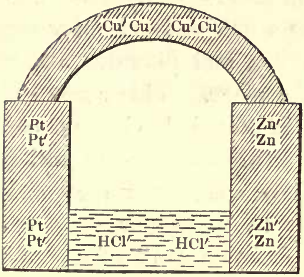


Fig. 2.

Here, then, we have eight molecules of different kinds, whose changes we propose to follow. And what are these changes? The first change is, that a molecule of *chloride of zinc*, C*l'* Z*n*, is formed by the decomposition of the molecules of hydrochloric acid and zinc, which are contiguous to each other, and by the union of the chlorine, C*l'*, which is a positive element, with the negative element, Z*n*, of the zinc molecule. (This molecule is formed because the negative element of the zinc has a stronger affinity for the chlorine than the affinity which previously kept the chlorine in union with the hydrogen in the molecule of hydrochloric acid.) By this change, the negative element of the hydrochloric acid molecule, namely, hydrogen, H, and the positive element of the decomposed zinc molecule, Z*n'*, are set free; and other changes are involved. Other changes are involved, because these elements have affinities which must be satisfied. Following these changes, then, the liberated hydrogen re-acts upon the un-decomposed molecule of hydrochloric acid, decomposes it, forms a new molecule of this acid by uniting with the chlorine, and liberates another element of hydrogen in its place. This second element of hydrogen, thus liberated, having no chlorine element with which to unite, seeks to satisfy its affinities upon the positive element of the platinum molecule, which is next to it. (This conducts us from the acid to the platinum part of the circuit.) These affinities draw the hydrogen and platinum element together, not close enough to produce union, but close enough to liberate the positive element of the platinum molecule from the negative element with which it was formerly united, and then this negative element is left free to act upon the molecules beyond. Free to act in this way, it decomposes the next platinum molecule, forms a new molecule by uniting with the liberated positive element, and liberates the negative element. This latter element having no proper mate (for we are now brought to the upper part of the circuit), endeavours to get one from the adjacent copper molecule, and its attractions, though not sufficient to produce union, are sufficient to liberate the positive element with which it was formerly united. This liberates a negative copper element, and this element immediately decomposes the next copper molecule, giving rise to a new molecule by uniting with the liberated positive element, and liberating the negative element. This liberated negative element of the last copper molecule acts upon the contiguous zinc molecule, as the negative platinum element did upon the contiguous copper element; and the result is, that the zinc molecule is decomposed, the positive element tending to unite with the copper negative element, and the negative zinc element uniting to form a new molecule with the zinc positive element of that molecule which had been decomposed by the chlorine, and whose negative element had gone to form the molecule of chloride of zinc, with whose formation we started in our course round the circuit. And thus we have travelled round the circuit to the point from which we started. This, however, is not the whole case. We have spoken of decompositions and recombinations starting from the molecule of chloride of zinc, and travelling in *one* direction around the circuit to the same point; but this is not all. On the contrary, these decompositions and recombinations travel in *both* directions. We have spoken of the changes induced by the hydrogen, but we might, with equal propriety, have pursued a contrary course, and traced the changes induced by the positive zinc element which was liberated when the molecule of chloride of zinc was formed. We might have traced the element as acting upon the contiguous zinc molecule, decomposing it, forming a new zinc molecule, and liberating another zinc positive element. We might have traced this element setting up corresponding changes, molecule after molecule, first in the copper, then in the platinum, and last in the hydrochloric acid, until we have travelled through the whole circuit, and returned to the point from which we started. So that, in fact, we may suppose each molecule, as it were, to be acted upon at both sides at once, and pulled asunder with a double power. This is the true conception, and this conception it is which enables us to understand the readiness with which the decompositions of which we have spoken are effected. The hydrogen which is liberated from the first molecule of hydrochloric acid when the molecule of chloride of zinc is formed, must decompose the second molecule of hydrochloric acid; not because its affinity for the chlorine of this molecule is stronger than that of the hydrogen previously combined with it, but because the hydrogen is being pulled away from the chlorine in the contrary direction by the attraction of the platinum element beyond. It is difficult to explain this idea in words; but it is sufficiently simple in reality, and there is nothing in it which is not quite consistent with the chemical hypothesis. It is difficult to explain the idea in words, but there is less difficulty with diagrams, and we think the two following diagrams, with a little attention, will serve to express the changes of which we have already spoken. The diagram on the left hand, which is merely a repetition of the one already given, represents the time before the formation of the molecule of chloride of zinc; the diagram on the right hand represents the changes which have taken place after the formation of this molecule. It is not possible to represent these changes in progress, but it is enough to remember that, originating in the formation of the chloride molecule, they start simultaneously from each side of the molecule and travel in opposite directions around the circuit to its other side, and that they issue in the re-arrangement of all the intervening elements into new molecules.

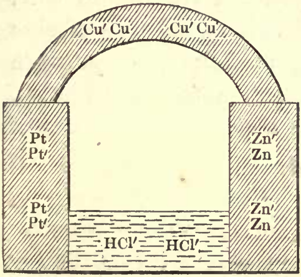


Fig. 3.

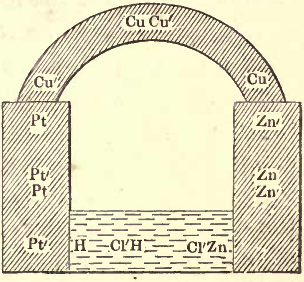


Fig. 4.

In order to understand the next change we must have recourse to another diagram. The change is this. The negative element hydrogen tends, we have said, to unite with the positive element of the platinum molecule next to it, but it only tends. The affinities between the metal and gas are not strong enough to secure union, and the primary result is, that the hydrogen escapes as gas,—a fact which we indicate in the following diagrams by placing its symbol above the line, with an arrow to indicate this upward tendency. Escaping in this way, the hydrogen liberates the positive platinum element, with which it had tended to unite, and this element acting upon the contiguous molecule, initiates a series of decompositions and re-combinations which traverses the rest of the circuit, and ends in the restoration of all the molecules to the condition in which they were before the formation of the molecule of chloride of zinc, with this only difference, that the positive element of the zinc molecule, whose negative element went to form the molecule of chloride of zinc, is left by itself. The molecule of chloride of zinc takes no part in these changes. Like the hydrogen element of which we have spoken, it escapes out of the circuit, only falling as a precipitate instead of rising as a gas,—a fact which we indicate by placing the symbols below the line, with an arrow to indicate the downward tendency. (The molecule of chloride of zinc may be supposed to take no part in the changes of the rest of the circuit, because the affinities of the component elements are too strong to allow the requisite decompositions and recombinations.) These changes may be thus represented—the first diagram being a repetition of the last.

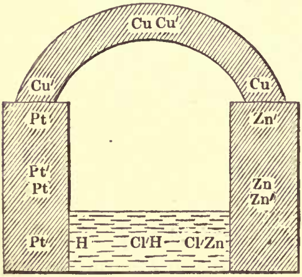


Fig. 5.

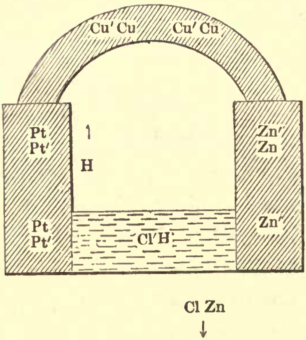


Fig. 6.

These changes being completed, they begin again by the formation of a second molecule of chloride of zinc. This is formed, as before, by the union of the positive element (chlorine) of the remaining hydrochloric acid molecule with the negative element of the remaining zinc molecule, and consequently, the hydrochloric acid and zinc molecule are both decomposed. The negative element of the hydrochloric acid (hydrogen) is thus set at liberty, and so is the positive element of the zinc molecule, and the result is a double train of decompositions and recombinations, such as that we have already described. Thus: —

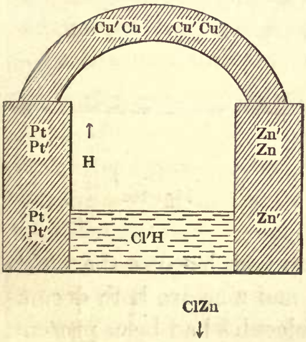


Fig. 7.

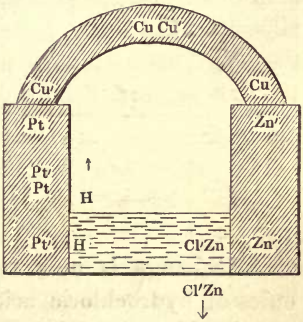


Fig. 8.

The next change is also a repetition of that which has been already described. This change begins by the escape of the hydrogen which for a moment tended to unite with the positive element of the contiguous platinum molecule, and by the precipitation of the molecule of chloride of zinc; and it ends by restoring the original molecular arrangement of the platinum and copper, and by isolating the positive elements of the two zinc molecules whose negative elements have gone to the formation of the chloride of zinc molecules. The causes of these changes are the same as those which operated previously. Thus:—

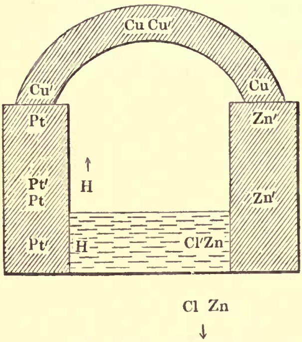


Fig. 9.

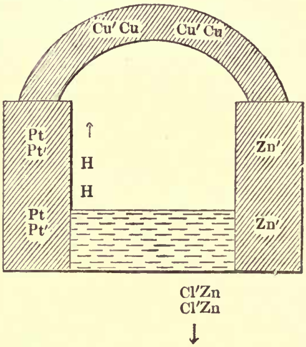


Fig. 10.

All change is now at an end, because the molecules of hydrochloric acid and zinc are both decomposed. If more of these molecules had been present, these changes would have been repeated,—a zinc positive element being left behind for every hydrogen element which escapes as gas, and for every chloride of zinc molecule which is precipitated. These changes are simply repeated, and it would only confuse matters by following them further. Nor are the changes really different when other exciting fluids are substituted for hydrochloric acid, though the expression of them may be rendered a little more complicated by the introduction of secondary changes. In short, there is nothing in the *theory* of the galvanic circuit which may not be reduced to the chemical hypothesis.

But, it may be asked, are not the forces concerned in the galvanic circuit of far higher intensity than ordinary chemical forces? Are they not proved to be of far higher intensity by the fact that a plate of amalgamated zinc and another of platinum may be immersed in hydrochloric acid without any sign of chemical action, so long as the plates are kept apart; but that active decompositions begin the moment they are brought into contact? There is no doubt that this is the case; but there is no reason, as Dr. Graham has shown, for calling in other than chemical forces to explain the phenomena. Suppose this case. Let a plate of amalgamated zinc and a plate of platinum be immersed in hydrochloric acid, and arranged in such a way that the two metals do not touch each other directly. Under these circumstances, the chlorine, C*l*′, of the hydrochloric acid, HC*l*′, and the negative zinc element, Z*n*, of the zinc molecule, Z*n* Z*n*′, have very strong mutual tendencies to combine and form a molecule of chloride of zinc, C*l*′ Z*n*; but these tendencies are not strong enough to rupture the ties which bind the chlorine to the hydrogen in hydrochloric acid, and the negative zinc element to

The forces concerned in the current are not of greater intensity than chemical forces.

the positive zinc element in the zinc molecule. But all is changed when the circuit is completed by bringing the zinc and platinum plates into metallic contact, for then the molecular changes of which we have just been speaking are transmitted simultaneously in both directions along the circuit; and the result is that, at one and the same time, the chlorine is more or less liberated from the hydrogen with which it was previously united, and the negative zinc element is more or less liberated from the positive zinc element with which it was previously united; and being thus liberated, the chlorine and the negative zinc element are more at liberty to obey those mutual tendencies which would cause them to unite in a molecule of chloride of zinc. All this will appear more intelligible with the help of the two following diagrams:—

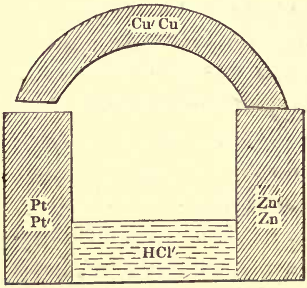


Fig. 11.

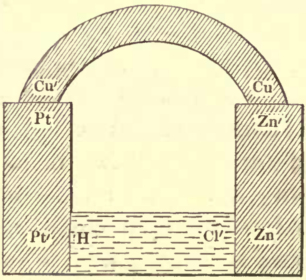


Fig. 12.

The first of these diagrams represents the circuit open; the second represents the circuit closed. The case is not at all complex; and a very little consideration will serve to show that the chlorine Cl', and the negative zinc element, Zn, must have more marked tendencies to unite with each other when the circuit is closed than when it is open. When the negative zinc element, Zn, tends to unite with the chlorine, Cl', it equally tends to leave the positive zinc element, Zn', with which it was previously united; and this positive element is thus left to exercise its peculiar affinities upon the contiguous molecules. When, on the other hand, the chlorine Cl', tends to unite with the negative zinc element, Zn, it equally tends to leave the hydrogen with which it was previously united; and this hydrogen is, therefore, at liberty to exercise its peculiar affinities upon the contiguous molecules. And what is the result? The result is a series of decompositions and recombinations which travel simultaneously in opposite directions around the circuit. Passing to the right, the positive zinc element, Zn', which yields the negative zinc element, Zn, with which it was united, to the stronger affinities of the chlorine, Cl', tends to unite with the negative element, Cu, of the contiguous copper molecule, liberating the positive element, Cu'; this positive element tends to unite with the negative element, Pt, of the contiguous platinum molecule, liberating the positive element, Pt'. This positive element tends to unite with the contiguous hydrogen element, H, of the hydrochloric acid; and thus the chlorine, Cl', which was previously united with the hydrogen, is left at liberty to unite with the negative zinc element, and form the molecule of chloride of zinc, C*l′* Z*n*. Passing to the left, the hydrogen which is abandoned by the chlorine for the stronger attraction of the zinc, is found to initiate a similar series of changes. Abandoned in this manner, the H tends to unite with P*t′*, liberating P*t*; P*t* tends to unite with C*u′*, liberating C*u*; C*u* tends to unite with Z*n′*, and thus Z*n* is left at liberty to unite with C*l′* and form a molecule of C*l′* Z*n*. When the circuit is closed, therefore, we have to do, not only with certain affinities, by which the C*l′* and Z*n* incline to leave the elements with which they were previously in combination, and to unite with each other, but we have also a double transmission of molecular changes around the circuit, by which the C*l′* and Z*n* are left more at liberty to obey their natural affinities by the withdrawal of the elements which had previously occupied these affinities. But when the circuit is left open the transmission of these changes is impossible, and the C*l′* and Z*n* are therefore prevented from fully yielding to their natural affinities, because these affinities are already occupied by other objects. The case, in fact, is plain enough, and the decompositions and recombinations *must* be more energetic when the circuit is closed than when the circuit is open; but in neither case is there any necessity to invoke to the explanation the help of other than simple chemical powers.

Nor is there any reason to believe that the laws of chemical affinity are ever suspended in the galvanic circuit, and other laws introduced in their stead. There is, indeed, a well-known experiment in which an alkali, in apparent violation of these laws, appears to traverse an acid without combining with it, but where, in reality, the alkali traverses the acid *by combining* with it on the way. In this experiment three cups, placed side by side, are put in connexion by pieces of lamp cotton soaked in solution of sulphate of potass.

The laws of chemical affinity are never suspended in the current.

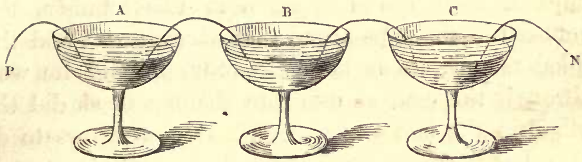


Fig. 13.

The cups A and C are filled with a solution of sulphate of potass; the cup B with dilute sulphuric acid; the positive electrode of a galvanic battery, P, is then dipped in A, the negative electrode, N, into C, and the preliminary arrangements are complete. In ordinary language, a positive current now enters at P and escapes at N, traversing the three cups on its way; and the result is, that the sulphate of soda in the two end cups, A and C, is decomposed, and that free alkali is found in C, and free acid in A; while the sulphuric acid in the central cup does not appear to be affected in the least. In other words, some of the liberated alkali would seem to have left the cup A, and gone through the acid in the central cup into the cup C, without combining with the acid. But this is not the explanation, and that it is not we may see by modifying the experiment. The three cups are still placed side by side, and connected by similar pieces of lamp-cotton; only now these pieces are soaked in solution of chloride of barium instead of sulphate of potass. The central cup is still filled with sulphuric acid; but the cups A and C are filled with the same solution as that with which the connecting pieces are soaked—chloride of barium. On passing the current in the same direction through the cups connected and charged in this manner, the solution in the cups A and C is decomposed, and the alkaline earth, baryta, endeavours to find its way through the central cup into the cup C, as did the alkali in the last experiment. It endeavours to do this, but it does not get beyond the central cup. It does not get beyond the central cup, because the alkaline earth, baryta, forms an insoluble precipitate with the sulphuric acid contained in this cup. Instead of there being no apparent change, as in the other experiment, the sulphuric acid in the central cup becomes milky with this precipitate as the current passes. This fact, then, shows very clearly that there was no suspension of chemical affinities in the former experiment; and it affords the strongest possible presumption that the soda passed through the acid in the central cup, not in violation of chemical laws, but in obedience to these laws;—that is, by first combining with, and then leaving the acid, in direct obedience to the overruling chemical affinities of the current itself.

It would also seem that the peculiar *transfer of matter* which is exhibited in this experiment and in many others, may be accounted for by ordinary chemical laws, and by these laws only. This transfer may be well illustrated by the last experiment; but it will be perhaps better to have recourse to a beautiful experiment by Dr. Faraday, in which a battery is made to terminate by silver electrodes in fused chloride of silver. In this case, as the current passes, there is apparently no change in the fused chloride of silver, but the positive electrode is found to grow and the negative electrode is found to waste, and this growth and waste are proportionate to each other. How, then, is this? The explanation is simple if the chemical theory be adopted, but otherwise it is altogether inexplicable. According to this view, the silver molecule in leaving the negative electrode takes the chlorine from the contiguous molecule of chloride of silver, and sets the silver of this molecule free. This silver acts upon the next molecule in the same manner, appropriating the chlorine, forming a new molecule of chloride of silver, and setting the silver free. This silver acts upon the next molecule of chloride of silver, and setting silver free, the liberated silver acts upon the next molecule in the same manner; and so on from molecule to molecule, through the chloride of silver, until the silver of the last molecule, having no chlorine to unite with, is precipitated upon the positive silver electrode. Thus, for every molecule which wastes away from the negative electrode, every intermediate

The transfer of matter in the current to be referred to ordinary chemical changes.

molecule of chloride of silver must be changed, and *pari passu* with this wasting and change must be the growth of the positive electrode. Nor is the apparent absence of any change in the fused chloride of silver between the electrodes any objection to this view, for there was the same absence of apparent change when soda was made to pass through acid in the last experiment, and yet the existence of this change was demonstrated when it was attempted to pass baryta. The latter experiment, indeed, not only demonstrates the existence of hidden change, but it shews that this change is chemical in its character; and hence it is scarcely possible to doubt that there are similar hidden changes in the fused chloride of silver, and that the silver is carried from one electrode to the other by these changes. Certainly this explanation is sufficient; and, as certainly, none other has been offered.

It is more difficult to account for the transfer of matter by the current through aëriform media, but still no new explanation appears to be necessary. This transfer is exhibited in various ways. It is seen in the colour of the spark when metallic electrodes are used, for this colour is the same as that of the flame of the same metal in common combustion. Thus, iron gives a sparkling red flame, silver a green, and zinc a blue. Here, then, we have evidence both of transfer of matter and of the means of transfer, for combustion is a known chemical process. But there are other kinds of transfer which are not so easily understood. When a voltaic current is discharged between charcoal electrodes, the charcoal is carried over bodily, one electrode being hollowed out as the other is elongated, just as was the case with the silver electrodes in fused chloride of silver. How, then, is the charcoal carried over? Is it by progressive combinations with the intervening molecules? The premises certainly warrant this conclusion, and there is no other explanation to be offered. When a voltaic current is discharged from zinc electrodes, across an exhausted receiver, or a receiver full of nitrogen, the discharge is luminous, and the zinc is deposited as a fine black powder of metallic zinc upon the sides of the receiver. The light of this discharge appears to be that of common combustion; but this it cannot be, for there is no oxygen to enkindle it. The black powder, moreover, burns in the open air when it is touched by a lighted match, and by this means is converted into white oxide of zinc—a plain proof that it could not have burnt previously in common combustion. Again, when the current is discharged between iron electrodes under the same circumstances as the last, the results are similar. Metallic iron distils, and may be detected as Prussian blue upon the sides of the receiver by washing them with a solution of ferrocyanide of potassium, and therefore the luminosity of the discharge in this case could not have been owing to common combustion. What, then, is the nature of the electric flame in the exhausted receiver and in nitrogen? What is it in the exhausted receiver? Is it the result of chemical changes among the molecules of the metal itself, such as those into which Dr. Graham has initiated us? What is it in nitrogen? Is it the sign of chemical changes between the metal and gas, of which we have yet to learn the nature? These are questions for future inquiry; but we need not wait until they are solved, for permission to infer that the transfer of matter in the electric current is nothing more than the natural consequence of chemical action. All the facts up to the present point are in favour of this conclusion.

Up to this point, then, everything tends to show the identity of electrical and chemical action, and the mysterious *current* appears to have nothing about it which may not be accounted for on this hypothesis. The current, indeed, appears to be nothing more than chemical action beginning at a certain point and propagated from this point around a circle in both directions at the same time. The current appears to be nothing more than chemical action; but because this action is propagated in a circle from one point in both directions at the same time to the same point again, each molecule in the circuit is acted upon from both sides at once, and, being thus acted upon, decompositions and combinations are effected, which would not be possible if there was no circular action, as under ordinary circumstances. In a word, the current appears to be nothing more than chemical action, but it is chemical action greatly intensified. Nor does it follow from this view of the current, that there should be an actual transfer of matter throughout its length. The hydrogen of the decomposing hydrochloric acid in the galvanic circuit, for

The reason why chemical forces are intensified in the current.

instance, does not move along the current beyond a certain point, but it presently escapes as gas. Its affinities for the platinum, and those of the platinum for it, are not sufficient to cause it to traverse the metal. And so also, in the experiments where the discharge is made across an exhausted receiver, or a receiver full of nitrogen, and where the metallic particles collect upon the inner surface of the glass, the affinities between these particles and those of the glass are not sufficiently marked to cause the former to traverse the latter. These metallic particles escape out of the circuit for the same reason and almost in the same way as did the hydrogen. There are interruptions, then, to the continuous propagation of chemical action around the circuit, and what the effects of these interruptions must be, it is not easy to say. They must certainly diminish the amount of action, but on the other hand they may be necessary to give rise to the phenomenon called *tension*. Without this retardation of the current, indeed, the motion might be so rapid as to escape our notice. We might only be conscious of chemical changes effected instantly and as by magic, and we might have been altogether ignorant of the process which we call electricity.

Elucidation of the phenomenon called tension.

There are, however, many facts which remain to be considered before we can hope to be able to answer the question, proposed at the outset of the inquiry — what is electricity? We have spoken of certain molecular movements, but we have not yet attended to those marked movements of attraction, quasi-repulsion, and rotation, which are so very characteristic of electricity. We have not yet spoken of the light and heat associated with electricity. And yet all these phenomena must be considered, before we can furnish the answer to the question, what is electricity?

Electrical attraction and repulsion (?) to be referred to chemical changes.

The attractions and apparent repulsions of electricity are very mysterious phenomena, and it is not easy to decide upon the best mode of investigating them; but it is perhaps the best to begin with those which are exhibited when electrical currents are passed in the same or in different directions through wires which are parallel to each other, and moveable.

Now, when currents are passed through wires arranged in this manner, we find that the wires approach each other when the currents pass in the same direction, and recede from each other when the currents pass in opposite directions. The wires attract each other in the first instance; the wires seem to repel each other in the second instance—*seem to repel,* for we shall find hereafter that it is not quite so certain that the wires repel as that they recede from each other. How, then, is this?

The reason why the wires attract each other would seem to be found in the fact that the current is not confined to the wire. Now that this is so, is evident. In the ordinary coil-galvanometer the passage of a current through one coil gives rise to a current in the companion coil. If the conductor be coiled into a tubular helix, as in an experiment we shall have to dwell upon presently, and a bar of iron or steel introduced into the core, the magnetic properties of the helix, when a current is passed through it, are found to be reproduced in the bar by the induction of corresponding currents around it. The magnetic needle, moreover, detects the presence of currents in the neighbourhood of a conductor similar to those which are passing through the conductor at the time. Hence it is a fair inference that the current which passes through the wire is not confined to the wire, but that it overflows to a greater or less distance from the wire. When two wires are placed parallel to each other, and a current is passed through each in the same direction, the results then are similar. In neither case is the current confined to its proper wire; and in reality each current must be supposed to pass through the other wire and its immediate neighbourhood as well as through its own wire and the immediate neighbourhood; and thus, mutually overflowing, the result must be that each current will co-operate with and intensify the other. This must be the result, for it is an ascertained fact that currents will intensify each other when passing in the same direction, and neutralise each other when passing in contrary directions. And if all this be so, it follows from the premises that the wires will attract each other when the currents pass in the same direction. What are these currents? They are composed of molecules, which molecules have common chemical virtues. The molecules may be composed of very different substances, but they all agree in that their corresponding elements are turned in the same direction. In this, which is the essential point, they are all *similar*, and being similar, what will be their natural tendencies? This is the question. Will they attract each other or will they not? There is no doubt that similar molecules under other circumstances will attract each other. When, for example, two different kinds of salts are mixed together in solution, we know that they will crystallise separately, the similar molecules attracting each other. There is no doubt of this; and hence the presumption that the similar molecules in the two wires, and in the parts surrounding them, *ought* to exercise reciprocal attraction; for the whole burden of the previous evidence has gone to show that there is an intimate if not inseparable connexion between chemical and electrical action.

It is more difficult to explain why the wires should recede from each other when their currents are in contrary directions; but the explanation will in all probability be found in a similar process of reasoning. When two different kinds of salts are mixed together in solution, like crystallizes with like. Similar molecules attract each other. But is this all? Do dissimilar molecules repel each other at the same time that similar molecules attract each other? If they do, then it may be argued that the dissimilar molecules of the the two wires and the surrounding media, when currents are passed through the wires in contrary directions, will repel each other, and this for the same reason that the molecules of dissimilar salts repel each other.

The existence of true electrical repulsion questionable.

But it is doubtful whether a real repellent influence is at work in either case, and certainly such influence is not necessary to explain the phenomena. Simple attraction will explain the phenomena of crystallization, and it will also explain why the wires recede from each other when their currents are contrary. What are the simple facts in the latter case? The facts are, that each wire conveys a current which overflows as far as the other wire, and the parts surrounding. The results are also simple; for, overflowing in this manner and meeting, each current must exercise a certain amount of neutralizing influence upon the other. It follows, also, that this neutralization will take place principally in the space between the wires, and that there will be little or no such neutralization beyond the wires. There will be little or none beyond the wires, because the currents overflowing from either wire in this direction cannot be interfered with by the current overflowing from the other wire —cannot be interfered with, because the currents overflowing from each wire into the intervening space had neutralized each other, and left a space over which no current could pass. And being so, it is doubtful whether a real repellent influence is concerned in causing the divergence of the wires, for this divergence may be accounted for, with equal readiness, by the attractive forces which must be at work.

On the sides of the wires which are opposed to each other, the currents spreading from each wire clash and are neutralized, and there will be in consequence an absence of all action, attractive or otherwise, across the space intervening between the wires; but on the sides of the wires which are not opposed to each other, that is on their outsides, there will be a mutual attraction between the molecules of the current in the wires and the molecules of the currents which are overflowing beyond the wire, and the effect of this mutual attraction will be to cause the wires to recede from the intervening space in which there is an absence of all action. This will be the effect, we say; for after what has been said we may safely assume that the molecules of the current in each wire will attract and be attracted by the molecules of the currents which proceed in the same direction on the outside of the wire; for it is a law without exception that all currents passing in the same direction attract each other.

In this explanation we assume that the mutual relations of the *molecules* are different from the mutual relations of the *elements* of these molecules. In the latter case unlikes approach each other, and likes recede from each other; in the former case likes approach each other, and unlikes recede from each other. But all this is quite in accordance with the teachings of chemistry. Thus, when soda and sulphuric acid are mixed together, the *dissimilar elements* of acid and alkali attract each other and unite to form the molecule of sulphate of soda, and then the *similar molecules* of sulphate of soda seek each other and unite to form the crystals of this salt. We also assume that molecules of very different substances may be *similar* electrically. Thus, the molecules in different parts of a galvanic circuit are of very different substances, but they are all similar electrically, in that they have all the same binary constitution, with their corresponding elements all turned in the same direction.

It would seem, therefore, that we may find the physical explanation of the movements of which we have been speaking in common chemical phenomena, or rather in that common law to which the phenomena of chemistry and electricity are, in all probability, alike subject. And this is an important point; for in the simple fact that currents passing in the same direction attract each other, and that currents passing in opposite directions recede from each other, we find the clue to the interpretation of those phenomena of electrical and magnetical motion which have now to be considered.

In pursuing our inquiry, it is desirable to realize in some degree the nature of that intimate connexion which has been shown to exist between electricity and magnetism; and in order to this, we may ponder with advantage upon the phenomena which are exhibited in a moveable spiral conductor during the

The connexion between electricity and magnetism.

passage of a current. The experiment is simple and familiar. The instrument by which it is made

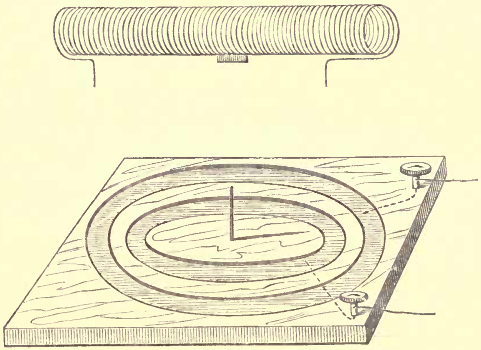


Fig. 14.

consists of two parts—the moveable spiral conductor, and an appropriate wooden stand. The moveable conductor is a coil of insulated copper-wire, with the ends arranged as in the figure. The stand is furnished with two concentric troughs (each of which is in connexion with a binding screw) and a central pivot. When in position the moveable spiral conductor is balanced horizontally upon the pivot, with the free ends hanging down, one into one trough, and the other into the other. In preparing for action the troughs are filled with mercury, and the electrodes of a battery are connected with the binding screws; and when this is done, the moveable conductor becomes part of the circuit, the current entering and leaving it by the ends which dip into the mercury contained in the troughs.

When this is done, the moveable conductor becomes part of the circuit; and what is the consequence? The consequence is twofold. In the first place, the conductor oscillates backwards and forwards until at last it rests in the magnetic meridian; in the second place, the two ends exhibit the properties of magnetic poles—the end which points to the north pole of the earth being attracted, that is to say, by the marked pole of a magnet, and *quasi*-repelled by the other pole; and, conversely, the end which points to the south pole of the earth being attracted by the unmarked pole, and *quasi*-repelled by the other pole. It is found also that the polar relations of the ends of the helix change places if the direction of the current is changed, and that the helix itself moves in an opposite direction to gain the magnetic meridian. And, last of all, it is found that a bar of iron or steel is rendered magnetic by being placed within the core of the helix. In a word, it is found that all the phenomena of magnetism may be exhibited in a moveable spiral conductor during the passage of a current.

Now this fact—which cannot be without important bearings upon the theory of magnetism—has naturally given rise to the idea that electrical currents circulate around every magnet in a direction which is transverse to the line connecting the two poles. It has naturally given rise to this idea, because the ends of the moveable helix are certainly endowed with the powers of magnetic poles, and because, as certainly, these powers are the consequence of the current which circulates in a direction which is transverse to the line connecting the two ends of the helix. It has naturally given rise to this idea, also, because it is possible to account for the possession of these powers by the simple and known reaction of electrical currents, if it be assumed that a similar current passes in the same direction around every magnet. When the marked pole of the magnet is held to the end of the helix which points to the south, the direction of the current around the end of the helix and around the pole of the magnet, according to the hypothesis, is similar; and hence attraction. When, on the other hand, the unmarked pole of the magnet is held to the end of the helix which points to the south, the currents in the two are in contrary directions, and for this reason they ought to recede from each other. And so also with the other poles. The meridional movement of the helix is also to be accounted for on the same principle, as we shall see presently; but, without proving this, we have seen enough to be able to assume, with some degree of probability, that a magnet is surrounded by electrical currents which pass in the direction which is transverse to the line connecting the two poles. And this is all we want to assume before proceeding to speak of the movement which has now to be considered — namely, rotation.

By a most ingenious course of reasoning, Dr. Faraday was led to expect that a magnet would revolve around an electrical conductor under certain circumstances; and he at length succeeded, not only in realizing his expectations, but in showing that the conductor would revolve around the magnet if the magnet were fixed and the conductor moveable.

The rotation of a magnet around an electrical conductor.

Many instruments are well calculated to show the revolution of a magnet around an electrical conductor, but none is more simple than one which is a slight modification of the instrument originally contrived by Dr. Faraday. In this instrument we have the conductor

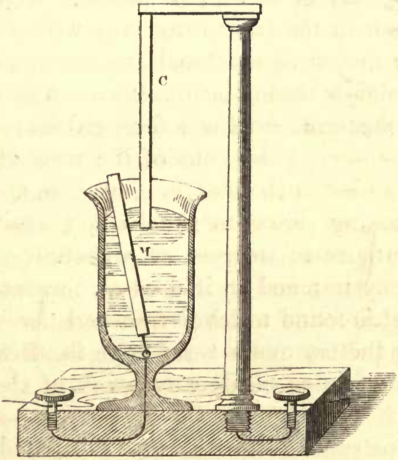


Fig. 15.

around which the magnet rotates, C, a small bar magnet, M, and a glass containing mercury. These are arranged as in the diagram. The lower end of the conductor is made to dip lightly into the surface of the mercury; the upper end is fixed to a metal arm projecting from the summit of a metal pillar whose base is in connexion with the binding screw on the right. The magnet is made to float vertically in the mercury contained in the glass by a piece of thread which passes from its lower end to a piece of wire which projects from the bottom of the glass, the piece of thread being of sufficient length to allow the upper end of the magnet to rise to some distance above the surface of the mercury. The wire to which the thread is attached is carried through the foot of the glass to the binding screw on the left. The instrument is connected with a galvanic battery by means of the binding screws, and, when the connexion is made, the current ascends the pillar, traverses the arm, descends through the conductor into the mercury, passes out of the mercury by the wire which pierces the foot of the glass, and so out by the binding screw to the battery again. The current pursues this course or a reverse course, as the case may be; and as it does so, the free end of the magnet is found to revolve around the lower end of the conductor, to the right or to the left, according to the direction of the current.

The rotation of an electrical conductor around a magnet.

Many instruments are also well calculated to show the revolution of an electrical conductor around a magnet, but none is better calculated for the purpose than one which is very like the last in form, and which is essentially like that which was originally contrived by Dr. Faraday. Here we have the same general arrangement as in the last instrument, with this dif-

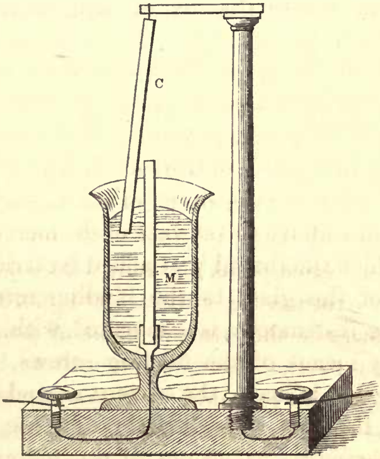


Fig. 16.

ference, that the conductor, C, is moveable and the magnet, M, fixed. The conductor hangs from the end of the supporting arm by means of a small piece of wire. The magnet is fixed by putting its lower extremity into a small socket-prolongation of the wire which passes through the foot of the glass from the binding screw on the left. The connexion with the battery is made as before, and when it is made, the conductor, C, is found to revolve around the vertical magnet, to the right or to the left, according to the direction of the current.

How, then, are we to explain these extraordinary movements? M. Ampère, we answer, has furnished the clue to the explanation, and we now know that the movements must result from the reactions which necessarily take place between the current surrounding the magnet and the current which streams from the conductor to the magnet.

In explaining the movement of a magnet around a conductor, it is necessary to bear several things in mind. It must be borne in mind that the currents of the magnet and conductor are not confined to these bodies; but that they extend to an indefinite distance beyond them, in, as it were, an atmosphere of currents. (See p. 56.) It must be borne in mind that these overflowing currents are more disposed to pass towards the nearest point of neighbouring bodies than to the space between these bodies — a fact which is well exemplified in the working of the common electrical machine. It must be borne in mind that a current may overflow indifferently from the conductor to the magnet, or from the magnet to the conductor, but not in both directions simultaneously, for it is not possible that contrary currents can co-exist in the same place without mutual neutralization, or without the weaker giving place to the stronger. In explaining the movements of a magnet around a conductor we assume, then, that the currents of the magnet are not confined to that body, but that they extend indefinitely beyond it, in, as it were, an atmosphere of currents. We also assume that currents overflow, not from the magnet to the conductor, but from the conductor to the magnet, and that they converge upon the nearest point of the surface of this body. We assume this, because the currents from the conductor are the stronger, in that they represent the whole force of the galvanic battery with which the conductor is connected, and because they are capable of acting upon all bodies indifferently; whereas the currents of the magnet originate within the mere compass of that body, and are only capable of acting upon iron and a very few bodies besides. We assume these things, and the movements of the magnet follow as a matter of course.

Suppose C and M to be transverse sections of the conductor and magnet respectively; suppose the arrows *a b*, *a′ b′*, *a″ b″* to be different parts of the current overflowing from the conductor and converging to the nearest part of the magnet; suppose the arrows *c d*, *c′ d′*, *c″ d″* to be different parts of the current surrounding the magnet, and what will be the result?

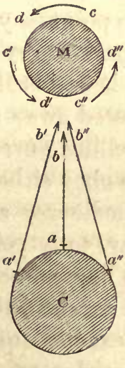


Fig. 17.

The result will be certain dissimilar lateral reactions between the currents, by which reactions the magnet is carried transversely towards the left. There will be no reaction in the median line itself, that is in the line of the arrow *a b*, because this line is the plane of inaction between the opposite reactions of the two sides. There will be attraction to the left of the median line, because the reacting currents on this side, as is indicated by the arrows *a′ b′* and *c′ d′*, are passing in the same direction, in that they are passing towards the same angular point. There will be *repulsion* (it is said) to the left of the median line, because the reacting currents on this side, as is indicated by the arrows *a″ b″* and *c″ d″*, are passing in opposite directions, in that one is moving towards the point from which the other is passing. According to this explanation, therefore, the magnet is simultaneously drawn and pushed in diverging directions towards the same side, that is, towards the left. It is drawn down to a point (say *e* in Fig. 18.) which is somewhere in the space between the attracting currents *a′ b′* and *c′ d′*; it is thrust to a point (say *f*) in a line which is directed away from the space which is between the repelling currents *a″ b″* and *c″ d″*; and not being able to obey either impulse exclusively, it yields a joint obedience, and moves to *g*. It moves, that is to say, to a point in a line which is perpendicular to the line connecting the magnet and conductor, for it is assumed that the attractive and repellent forces are exactly equal, and that they are directed at similar angles on each side of this line. Thus: —

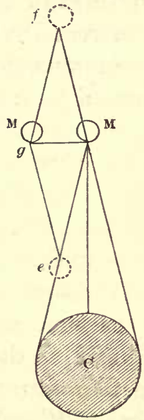


Fig. 18.

The magnet, however, is not strictly at liberty to yield to this impulse. On the contrary, it is so confined by the form of the apparatus as to be only capable of moving in a circle around the conductor, and therefore the impulse of which we have just spoken is expended in initiating this compound motion. This, then, is what takes place in the first instant, and this is what is repeated without change in succeeding instants so long as the reactions of the currents continue. It is repeated because the magnet carries its own currents along with it, and because the converging currents from the conductor do not cease to follow.

But it is very questionable whether this explanation holds good in all its details, and whether the direction in which the magnet tends to move is that which has been described. It is very questionable, because we are constrained to agree with those who discard the idea of a repellent force in electrical phenomena, and ascribe apparent repulsion to outwardly acting attraction. And certainly it is not

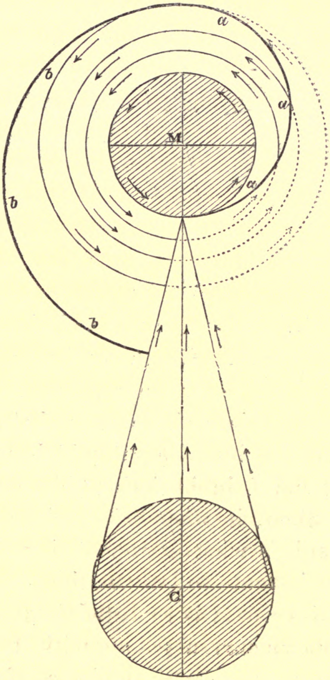


Fig. 19.

difficult to show that a repellent power is not necessary to explain the phenomena under consideration. Once more, then, let M and C be transverse sections of the magnet and conductor. Let the concentric circles surrounding the magnet be the extraneous currents of which we have spoken, and let the arrows indicate their direction. In like manner let the lines and arrows proceeding from the conductor to the magnet indicate the currents which are passing in this direction. Let it be supposed, then, that the reactions between the currents to the right, instead of producing repulsion, produce a greater or less amount of neutralization in both currents, but especially in the weaker currents, that is, in the currents surrounding the magnet; and let this neutralization diminish progressively as we pass away from the point where the currents from the conductor impinge. Let, moreover, the extent of this neutralization be indicated by the curved line *a a a*, and by the dotted lines and arrows to the outside of this line. On the other hand, let it be supposed that the effect of the reactions to the left of the converging currents is to intensify the attractive powers of the currents surrounding the magnet and in the magnet by the addition of the whole amount of the attracting power of the currents proceeding from the conductor; and let this intensification (which must diminish progressively as we pass away from the point where the currents from the conductor impinge) be indicated by the curve *b b b*. Let these things be supposed, and it is evident that the disturbed balance of attraction can only be restored (the magnet being alone moveable) by the motion of the magnet in the direction in which the attraction is now strongest.

What, then, we may now ask, is the direction in which the magnet will move under these circumstances, for move it must in order to gain the equilibrium of attraction? Under these circumstances, we answer, it will move somewhere towards the left. This is evident, and will appear to be so by glancing for an instant at the diagram. But what, we ask again, will be the precise direction of the motion? Will it be in a line which is at right angles to the line which connects the magnet and the conductor,—to the line, that is to say, which is the *radius vector* while the magnet continues to move around the conductor; or will it be in a line which is directed at an angle which is more or less than a right angle? The answer is not at all doubtful. The motion cannot be directed in a line which is inclined away from the conductor at an angle of more than a right angle; it cannot be directed at the right angle; but it must be directed in a line inclining towards the conductor at an angle of less than a right angle. This must needs be, if the intensification and neutralization of attraction resulting from the reaction of the current belonging to the conductor and magnet are equal; and that this is so will appear in the diagram, for the line of preponderating attraction, as is shown by the curves *a a a*, *b b b*, is a line which inclines towards the conductor at an angle which is less than a right angle. Or, if we consider the motion of the magnet in relation to a circle passing through the magnet and carried around the conductor as a centre, the motion must be, not in the tangent to the circle, but in the chord. Instead of being tangential, or in the line *a b*, the motion must be, if we may use the word, *subtensial;* that is, in the line *a c.*

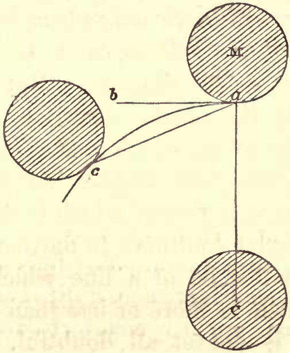


Fig. 20.

And this must always be the direction of motion. The amount of motion must vary in proportion to the degree in which the attraction acting upon the magnet is intensified on the one hand and neutralized on the other hand,—the amount being always directly proportionate to the degree; but the direction of motion must always be *subtensial,* when it is considered in relation to the imaginary circle which passes through the magnet and around the conductor as a centre.

Now it is not altogether a matter of indifference whether the direction of motion in this case is tangential or subtensial. If it is at right angles to the line connecting the magnet and conductor, the magnet could not move in a circle, except it were bound down by something which should discharge the office of a centripetal force, and thus rotation would be nothing more than an accident connected with the form of the apparatus. But if the magnet is set in motion in a resisting medium, by an impulse which is subtensial in its character, it follows that it must move eventually in a circular orbit around the conductor, or rather in a polygonal orbit which cannot be distinguished from a circle. In the first instance, the magnet may be carried by the impulse beyond the circle which would pass through its first position, but if it is so at first it is not so always. It is not so always, because the impulse fails as the distance from the conductor increases, until at last the impulse and resistance are so counterbalanced, that the magnet is carried into the circle which passes through the point from which the impulse last originated. And when this happens, the magnet must enter upon a circular, or quasi circular path, for the impulse can undergo no change so long as the distance from the conductor remains the same; and the distance must remain the same if the magnet is continually moved to different points in the same circle. The same result must also follow, if, on the other hand, the impulse is not sufficient to overcome the resistance so as to maintain a movement in a circular orbit; for in this case the magnet must continually approach the conductor by stopping at points within the circle, until the increase of impulse which is derived from the decrease of distance is sufficient to overcome the resistance and carry the magnet to the same distance from the conductor as it was when the impulse originated, and then, for the reasons already given, the movement in a circle must commence. A longer or shorter interval of time may elapse before this adjustment is effected, according as the impulse is powerful or feeble, but it must be effected in the end, and when it is, then the magnet must describe a circle around the conductor, the movement being to the right or left as the direction of its currents may determine.

In explaining the motion of a magnet around a conductor it is possible then to dispense with the idea of a repellent force, and explain all by the force of simple attraction. It is possible, indeed, to understand that a magnet might really circulate around a conductor, and not merely be driven along a circular path to which it was confined by the form of the apparatus; and thus, while it is possible to explain what was not before explained, the law itself is greatly simplified.

Nor is it different when the magnet is fixed and the conductor moveable; for the reactions of which we have spoken must operate upon the conductor as well as upon the magnet, and not only must the conductor move if it be moveable and the magnet fixed, but conductor and magnet must move around each other if both were free to move.

The rotation of an electrical conductor around an electrical conductor.

It is practically as well as theoretically certain that electrical currents will produce these movements of rotation when passing at right angles to each other, and this, therefore, is an argument that electrical currents do surround the magnet in the direction which has been supposed, and that the explanation of rotation which has been founded upon their supposed presence is tenable. That electrical currents will cause rotation when passing at right angles to each other has been abundantly demonstrated by Ampère, and one of the instruments by which this has been done is represented in the following diagram.

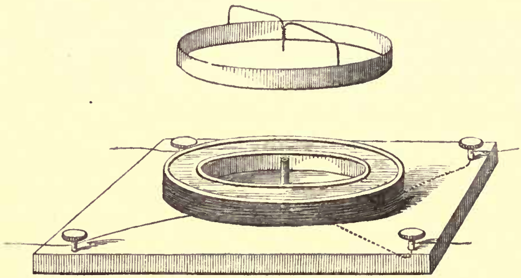


Fig. 21.

This instrument consists of two parts which are essentially distinct from each other. The first part comprises a copper ring-trough, a copper central pillar, and a copper hoop. The trough and pillar are fixed upon a flat stand, with the pillar in the centre. The hoop, which is furnished with a cross-wire and a pivot directed downwards, is detached. Belonging also to this part are two binding-screws, the one being connected with the trough, and the other with the central pillar. In preparing for action, the electrodes of a battery are connected with the binding-screws, the trough is filled with dilute sulphuric acid, and the hoop is placed with its pivot upon the central pillar and its lower edge in light contact with the sulphuric acid contained in the trough; and when all this is done the current may either pass to the trough, thence through the acid to the hoop, and so back to the other side of the battery, by way of the central pillar, or else it may pass in a contrary direction. This is one part of the instrument, and this is the direction which the current pursues in it. The other part of the instrument is a simple insulated copper-wire, coiled several times around the outside of the trough, and connected by its ends with the two binding-screws to the right. These binding screws are intended to receive the electrodes of a second battery. The instrument is therefore arranged so as to be open to two currents, and the current which passes through the coil is made to cross at right angles the current which traverses the hoop and trough. This is the arrangement, and the result of the arrangement is that the hoop is stationary when either current is passed separately, and that it revolves upon its pivot, to the right or to the left according to the direction of the current, when both currents are passed simultaneously.

The curious phenomena of rotation of which we have been speaking would therefore appear to be due to the reaction of cross currents of electricity; and hence we may adduce a strong additional argument in favour of the idea that a magnet is surrounded by electrical currents whose direction is transverse to the line connecting the two poles. But this is not all. On the contrary, there arise out of the same premises many ulterior considerations which are of vital importance in our present argument;—

and first of all, with reference to the phenomena of magnetism.

Influenced by many weighty arguments, of which some have been stated, M. Ampère arrived at the conclusion that magnetical phenomena are due to the circulation of electrical currents around the magnet; and by thus discarding the idea of any special magnetical agent, he greatly simplified the theory of magnetism. As left by him, however, the theory is still complex, and perhaps incomprehensible; for it assumes the continual presence in every conductor of a double series of currents, arranged cross-wise with respect to each other. But this is certainly not the final simplification of which the subject is capable.

In the experiment of the moveable spiral conductor, it was shown that the powers of the magnetic poles could be explained by the common reaction of electrical currents. The spiral conductor (which was in every respect a true magnet for the time being) gave evidence of *one* current passing along the wire which formed the coil; but of one only. Where, then, is the evidence in favour of the double series of currents? Now, the facts which remain to be considered, and which furnish the answer to this question, are the meridional movement of the magnetic needle, and the cross movement of the same needle when placed in relation to an electrical conductor; and these facts we now propose to examine.

When a magnetic needle is placed in the immediate neighbourhood of an electrical conductor, it arranges itself across that conductor. This is a familiar fact, and one not at all difficult to understand, if it be assumed that the needle is surrounded by transverse currents of electricity.

A magnetic needle must arrange itself across an electrical conductor.

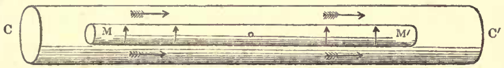


Fig. 22.

Let M M′ be a magnetic needle lying upon an electrical conductor C C′, and moving upon a central pivot the position of which is indicated by the dot. Let the currents in the conductor and the currents in the magnet travel in the direction which is indicated by the arrows placed upon each, and it is evident, according to the premises, that the currents will react upon each other until they are placed in the same direction; and that they cannot be placed

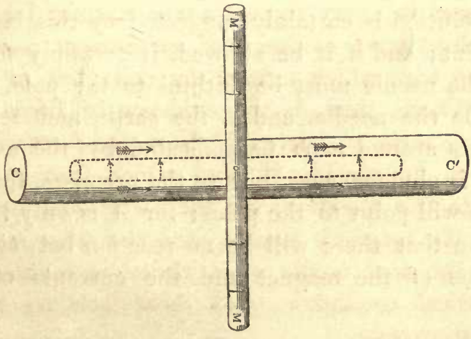


Fig. 23.

in the same direction until the needle has moved upon its pivot through a quarter of a revolution. It is evident, also, that these reactions must cease, and the needle come to a stand-still, when it has moved to this extent, because its currents are then in the same direction as those which pass along the conductor.

The cross movements of the needle under these circumstances, then, appear to be the natural consequence of the reaction of the currents which pass around the magnet and along the conductor; but it gives no support to the idea of a double series of currents, either in the magnet or in the conductor.

The magnetic needle must point to the poles of the earth.

But what of the meridional movement of the magnetical needle? How is this to be accounted for? Is it to be accounted for by supposing that electrical currents surround the earth in the plane of the ecliptic, and that the transverse currents of the needle react with these currents as they did with the currents of the conductor in the last experiment? This solution is certainly suggested by this last experiment; and if it be allowed, it certainly follows that the needle must be faithful to the pole. Let M M′ be the needle, and E the earth, and let the currents around each be indicated by the arrows, and it is obvious, according to the premises, that the needle will point to the poles; for it is only in this position that there will be no reaction between the currents of the magnet and the currents of the earth.

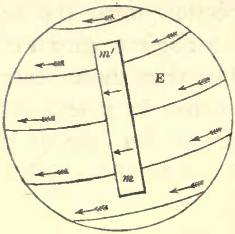


Fig. 24.

In fact, we know of no shadow of evidence in favour of the belief either in special magnetical currents or in special electrical currents, as concerned in the phenomena of magnetism; and, so far as we can see, all these phenomena may be traced to intelligible reactions between simple currents of electricity. So far as we can see, indeed, magnetism ceases to have any existence as a special force, and becomes a mere mode of electrical action.

No special electrical currents in a magnet.

Magnetism a mere mode of electrical action.

Now this is no unimportant conclusion, for by it we are enabled to clear up two residual difficulties. We have been obliged to infer the existence of chemical changes in metallic conductors during the passage of the electric current, from the peculiar constitution of the loadstone and of other magnetic salts. The argument was one of mere analogy. But if "magnetism" be a mere mode of electrical action, then these facts become so many direct proofs

The bearing of these considerations upon the theory of electricity.

And, first, as showing the presence of chemical changes in a metallic conductor during the passage of the current.

that there are these chemical changes in metallic conductors during the current; for they show that such changes are necessary to magnetism, which is another name for electricity.

Again, if "magnetism" be electricity, we see a way of solving that greatest of all magnetical riddles —permanency. In order to this, indeed, all that is necessary is to apply the theory of the Leyden jar. In this jar the charge is preserved by the mechanical interposition of the glass between the excited coatings. It is preserved because the glass presents a barrier to the reunion of those polar elements in the metallic coatings and elsewhere, which have been separated by the current, and whose separation and reunion is the current. In the loadstone and in steel the oxygen and carbon act (we may suppose) the part of the glass in the Leyden jar; and the "magnetism" is rendered permanent simply because these substances present a mechanical barrier to the reunion of the polar molecules of the iron. Iron very readily enters into the electric state, and as readily passes out of it. The elements of its molecules are peculiarly mobile. But if carbon be combined with iron, as in steel, the affinities of the molecules are occupied, and their ready decomposition and recombination is interfered with. Hence steel is an infinitely worse "conductor" than iron. But if the electric current be sufficiently strong to produce the necessary decompositions in the steel, the carbon still interferes with the recombinations. Like the glass of the Leyden jar, it mechanically

The loadstone and steel must retain their magnetic power.

prevents these recombinations. Under these circumstances there is not a *current* in the steel; but there is, as it were, a current dammed up,—a current "frozen into permanence." Again, the common oxides of iron, and other oxides, are not electrical "conductors" for the same reason that steel is a worse conductor than iron. The affinities of the iron elements are preoccupied by the oxygen; and the elements cannot yield themselves readily to the play of those chemical decompositions and recombinations which constitute the current. But if it happens that these molecules are decomposed after the fashion which obtains in the current, and the separated elements combined with oxygen, the separated elements are still able to react in some degree even after this combination; and the oxygen serves to perpetuate this condition by presenting a mechanical barrier to the reunion which would put an end to the reaction. And so also with the magnetic sulphuret of iron; for in this case the sulphur plays the part of the oxygen in the magnetic oxide, of the carbon in the magnetic needle, and of the glass in the Leyden jar. Upon this theory, indeed, all that is necessary to fix the phenomena of magnetism is to have some mechanical medium interposed between the polar elements of the molecules,—a medium sufficient to prevent the reunion of these elements, but not sufficient to prevent their mutual reaction. It is still the chemical hypothesis to which we have recourse for the explanation; and thus the loadstone becomes the real key to the mystery of electrical action. It is this stone which points the eye of the philosopher, no less than the eye of the mariner, to the star by which he can direct his course. It is of a truth the Philosopher's stone — a stone, not turning everything it touches into gold, but effecting a far higher transmutation than this — that of ignorance into knowledge.

But we are not yet at the end of the inquiry which can furnish an answer to the question what is electricity, though we have approached sufficiently near to this end to be able to conjecture what the nature of this answer must be. We have, indeed, still to consider the phenomena of electrical light and heat; and first with regard to the light.

The various arguments which connect the several forms of luminous "discharge" and "conduction" with ordinary "conduction" prepare us to expect that *electrical light* must be referred to chemical action. The arguments are so complete that others are scarcely necessary; but there is one of great beauty which has not been mentioned, and which ought not to be overlooked. This is to be found in the following experiment: — A wheel, with a written inscription upon one of its spokes, is placed upon an axle in the focus of a photographic camera, and arrangements are made for illuminating it when necessary with an electric spark. Having darkened the room, the wheel is then set in motion, and when the motion has at-

Electrical light must be referred to chemical action.

tained its highest pitch of velocity, the slide of the camera is raised, and the spark passed. The whole is the work of an instant; but there has been sufficient time to copy, not only the wheel, but also the inscription on the spoke. Now this copying must have been instantaneous, for if it had not been so the image would have been blurred by the motion of the wheel. The copying, also, must have been instantaneous, because the illumination was only instantaneous. There can, indeed, be no more beautiful illustration of the companionship between electrical light and chemical action than this; while at the same time the fact is well calculated to spiritualise, as it were, our conceptions of chemical action, and, by displaying its amazing subtleness and swiftness, to show its fitness for electrical purposes. Now the nerve of sight is endowed with the power of perceiving light, and this perception is the only notion it can form of any kind of action. In the operation for cataract, for example, the patient suffers pain as the knife divides the outer coat of the eye, but the sensation of pain is exchanged for that of light as soon as the instrument has penetrated to the retina or true visual surface. In this case the same action is attested by pain in one part of the frame, and by light in another part; and if so, why should it be otherwise in the case of electricity? What reason is there that the same action which produces the shock in the nerves of common sensation and in the muscles should not produce the sensation of light in the eye? There is no such reason to be met with, and, as there is not, the natural presumption is that electrical light is nothing more than electrical action, otherwise chemical action, attested by the eye.

And this, moreover, is the idea which we should derive from the consideration of the light which is derived from ordinary combustion, and from various other sources, for in all these cases the light is more or less obviously connected with chemical changes.

Now these changes, it must be remembered, are present, according to the premises, not only at the origin of the ray, but at every point of its course until it dies out in darkness. Actual waves of chemical change, and not mere ideal undulations in a hypothetical ether, spread abroad on all hands from the luminous focus, and there is no illumination beyond the waves. According to the premises, indeed, we must regard the illuminated object, whatever or wherever it be, as being for the time the seat of continual chemical changes, either between the molecular elements of different substances, or between (see p. 32) the molecular elements of the *same* substance.

Electrical heat must be referred to chemical action.

The phenomenon of *electrical heat* may be partly disposed of in the same manner as the light, but not entirely. The *sensation of heat*, in all probability, is nothing more than electrical action attested by a particular class of nerves; but this attestation is not sufficient to account for that seemingly repulsive power which is characteristic of heat, and which causes a solid to become a fluid, and a fluid a gas. This power is mysterious, but not unintelligible, and no new principle of interpretation is required for the explanation.

The expansive powers of heat to be explained on the same hypothesis.

In investigating the phenomenon of electrical heat, we are struck, first of all, with one circumstance, and this is that the degree of heat is apparently proportionate to the inadequacy of the conductor through which the current is passing. With an ordinary current scarcely any heat is given out when a thick wire is used as a conductor, but if this wire be divided, and the ends connected by a piece of fine wire, the latter wire is immediately heated, or even fused. It is the same also when a strong current is passed through a chain consisting of alternate links of thick copper wire and thin platinum wire; for in this case the platinum links become red hot, while the copper links are not appreciably affected except by contact with the other links. That the evolution of heat is in some degree connected with inadequate conduction is also shown in an experiment which is a modification of one which was originally used by Mr. Grove in the illustration of another subject. The instrument is an ordinary glass test-tube, across which are carried two wires of different sizes, one thick and the other thin. In using it, the tube is filled with water, and the ends of each wire are placed successively in connection with an appropriate battery. A current is thus passed, first through one wire, and then through the other, and the result is that a great amount of heat is given out when the current is passed through the thin wire, and scarcely any or none at all when it is passed through the thick wire. And this difference is very marked, for on passing the current through the thin wire the water in the tube may be made to boil with much activity.

But it may be asked how do these facts bear upon the seemingly repulsive power of heat? They bear, we think, very closely, for we can see nothing in this power which is not a natural consequence of electrical action under certain intelligible circumstances. What, we ask, is the electrical current? According to the premises, it is a definite series of chemical changes involving a distinct transfer of matter in space. It is not possible to conceive of ordinary chemical changes without certain changes of place in the elements combining or separating; and for the same reason it is not possible to conceive of the current without similar changes. The transfer of matter from one electrode to another, or across the fluid with which the battery is charged, are illustrations of this fact. What we have first to do, then, is to realise this idea of material transfer as necessarily connected with the current. According to the premises, moreover, it is not possible to regard the current as confined to the conductor. On the contrary, it is necessary to regard it as overflowing from the conductor to surrounding parts. Pass it must by one way or another, and, as it will pass most readily through the most open channel, it follows that the amount to which it will overflow will be in direct relation to the inadequacy of the conductor. Now what must be the consequence of this overflowing? Have the outward-bound currents the same characters as the main current? Do they, in like manner, involve the idea of onward transfer of matter? If they do—and most certainly the premises allow no other conclusion—then it follows that the substance of the conductor must tend to pass in an outward direction during the passage of a current, and that this tendency will be most marked when the conductor is inadequate, as in the experiment with the thin wire, for in this case the outward-bound currents will be more powerful. In other words, the effect of these outward-bound currents will, according to their force, be the same as those which are ascribed to the so-called repulsive power of heat—namely, expansion, fluidification, aërification. And thus it is possible to agree with Berzelius in regarding electrical heat and chemical heat as mere modes of the same action, while, at the same time, it is not impossible to dispense with a special repellent power in explaining the so-called repulsive effects of heat.

Nor is there anything contradictory to this view in the history of the heat which is derived from common combustion and other artificial sources, for in every instance the heat is more or less obviously referable to chemical action.

With reference to artificial heat, also, the same remarks have to be made as those which were previously made with reference to light, and chemical changes, according to the premises, are no less necessary for the transmission than for the origination of this action. According to the premises, indeed, heat could not radiate through the atmosphere, or penetrate anywhere, without the mediation of chemical changes of one kind or another. Indeed, we can form no conception of heat apart from these changes.

The whole history of electricity points to a central law which we will designate provisionally *the law of the laboratory*. Characters of this law.

In this way, step by step, we have arrived at a point from which we catch a glimpse of a central law. As we come along, the phenomena of electricity are seen to submit themselves to the law of chemical action, and magnetism and light and heat are found to become mere modes of electricity, while at the same time the idea of chemical action has become so comprehensive and general as to lose all proper speciality. In a word, electricity, magnetism, light, heat, and chemical action, have all merged into a common action—an action of duality, out of which arise under peculiar circumstances certain marked movements—an action which depends not upon incomprehensible imponderables, but upon certain definite and comprehensible properties of matter. All things have indeed combined to point to a law which is at once simple in its nature and manifold in its operations,—and this is the answer we get to the question proposed at the beginning—What is electricity?

What then? Is this law the law which dominates in nature? This is the question which we have now to ask, and which we propose to answer as best we

Has the law of the laboratory a wider scope?

can. Now there are several signs which seem to show that this law may be a cosmical law. Light, heat, and chemical power attend upon the force of gravity in the solar ray and render it difficult to regard this force as an isolated and independent power, and it is not easy to suppose that magnetism and electricity do not enter into the perfect idea of that law by which the earth is ruled. There are, indeed, many signs from which we should infer that the law of which we have been speaking has a wider scope than was at first apparent, and which encourage us to search whether it be so or not. Let us then brace our minds to the task of searching the evidence, and, trusting in a higher illumination than our own, let us begin by considering the *movements* of the heavenly bodies.

CHAP. II.

SEARCH AFTER A CENTRAL LAW IN SOME OF THE PHENOMENA OF NATURAL MOTION.

The laws of Kepler.

THE philosophical interpretation of the movements of the heavenly bodies began unquestionably when Kepler made the three great discoveries which are known as *Kepler's laws.*

The first of these discoveries is that the *radius vector* (or line which connects the planet or comet with the sun, and the satellite with its primary,) is carried over equal areas in equal times. It might be expected that this radius would have been carried over *un*equal areas in equal times, for the orbital velocity of the heavenly bodies is subject to considerable variation; but Kepler found that the radius increases in length as the velocity diminishes, and *vice versâ,* and that this counterbalancing between distance and velocity is such that the radius is always carried over the same area in the same time. The second of these discoveries is, that the planets and comets move in ellipses with the sun in one of the foci, and that the satellites describe a similar movement around their primaries. The third discovery, which is often spoken of as the harmonic law, is that the squares of the periodic times of the revolution around the sun are proportional to the cubes of the distance from the sun.

These discoveries were the fruit of most laborious enquiry. They were sifted out of myriads of other facts by a man of extraordinary patience and penetration. They are themselves facts of very high practical value, for by them astronomical predictions became possible; but they were mere isolated and empirical facts until Newton undertook to interpret them.

Interpreted by Newton, the true significance of Kepler's discoveries became apparent. The equable description of areas in equal times became a proof that the centre of these areas is the centre of the force or forces acting upon the planet or planetoid body. The fact became significant of law, but it did not declare the nature of the law. The elliptical form of the orbit with the sun or primary in the focus became a proof that the central force or forces acts or act with an energy which is inversely proportional to the square of the distance, increasing as the distance diminishes, and decreasing as the distance increases. And, lastly, the fact that the squares of the periodic times are inversely proportional to the cubes of the distance, became the proof that all the planets and satellites are retained in their orbits by the same force or forces, modified only by distance.

Newton's interpretation of the laws of Kepler, and Newton's philosophy of the heavens.

But Newton did not content himself with this interpretation. On the contrary, he laid down three laws or axioms, — the three laws of motion, as they are called,—and went on to explain by them the whole scheme of celestial motion. The laws are these.

The first is, that a moving body will move with uniform velocity in a straight line, and continue its motion for ever, unless it is acted upon by some external force. This is the necessary consequence of the *inertia* of this body. Without inherent capacity of action, indeed, this body remains for ever at rest if at rest, and moves for ever in a straight line if in motion and perfectly free to move. In itself the body is purely passive.

The second law is, that the change of motion which is caused when a moving body is acted upon by any force is the same as that which would have been produced if the same force had acted upon the same body during the state of rest.

The third law is, that action and reaction are equal; or, in other words, that the mutual action of two bodies upon each other is equal in degree and contrary in direction.

In applying these laws to the explanation of the movements of the heavenly bodies, it is assumed that space is free from everything which can offer resistance to the movements of these bodies, and that each body was originally launched into its orbit with a given velocity—a velocity varying for each body—by a force which ceased to operate as force from that moment.

Moving in free space, and set in motion in this manner, a planet, for example, tends to move for ever in a straight line; but instead of obeying this tendency it moves in an orbit around the sun, and by so doing shows that it has been deflected from the straight line in which it would move naturally, by a force which continually tended towards the sun. This centripetal force, moreover, is attractive in its character, because it tends to bring the planet towards the sun; its power is inversely proportional to the square of the distance, because the planet moves in an ellipse with the sun in one of the foci; and the same force attracts all the other planets and their satellites, because in all the square of the periods is inversely proportional to the cubes of the distance. The particular form of the orbit is determined altogether by the velocity with which the planet was originally launched into space. If the velocity were precisely balanced by the attractive force, the orbit would be a perfect circle, for at every point the planet would be bent down from the tangent of the orbit — the straight line in which it tends to move in accordance to the first law of motion — into the circumference of the circle. If the velocity was not precisely balanced by the attractive force, the orbit would be more or less eccentric.

If, for example, the original projection be such as to overbalance the centripetal force, the planet will at first tend to escape from that purely circular orbit in which it would have moved if the projection and the attractive force were exactly counterbalanced. At every successive moment, however, the planet must move with diminished velocity away from the sun, for the centripetal force will continually drag upon it and tend to bring it back towards the sun;

and thus the curve of orbital motion will be more and more bent until at last projection and attraction begin to operate in the same direction. Up to this time the orbital motion had been continually retarded by the centripetal force; now the case is altered, and the motion is progressively accelerated by the increase of centripetal force which arises from the diminished distance from the sun, until the superadded velocity is sufficient to overcome the central attraction, and carry the planet in the same direction and with the same velocity as when it began to move. If, on the other hand, the original projection be not sufficient to counterbalance the centripetal force, and maintain a purely circular orbit, the planet will at once begin to fall towards the sun, and this it will continue to do with continually increasing velocity until the superadded motion, arising from the increasing gravitation as the distance diminishes, is sufficient to overbalance the centripetal attraction and carry it in an outward direction. And then, as in the former instance, the centripetal force will begin to drag upon the planet, and retard its motion, until, regaining its former mastery, the planet is compelled to travel in the same direction and with the same velocity as when it began to move. The degree of orbital eccentricity must of course be proportionate to the disproportion which may exist between the motion of projection and the attractive force, and if this disproportion exceed a certain bound there may be no proper orbit at all, and, instead of moving in orbits of various eccentricity, the planet might imitate some of the comets, and describe hyperbolic or parabolic curves.

What, then, is the attractive force which plays so important a part in the formation of these orbits? Is it that force of gravity which causes a stone to fall to the earth? This question is a natural question, for the force is universal. It is this force which draws the bucket to the bottom of the well, which caps the mountain with clouds, and which steadies the car of the aëronaut as it floats high above the earth. Now this is a question which has been answered by comparing the space through which a stone falls to the earth in a given time, with the space through which the heavenly bodies fall in the same time from the tangents of their orbits. At the surface of the earth, then, the stone is found to fall through 193 inches in the first second; and what is this when compared with the distance through which the moon falls from the tangent of her orbit in the same time? On making the necessary calculations it is found that the moon does not fall more than the 0·0536th part of a single inch in this time, and therefore the attraction of the earth for the moon, as compared with the attraction of the earth for the stone, is in the ratio of 1930000 to 536, or 3600 to 1. In other words, the attraction of the earth, thus measured, is 3600 times less at the the moon than upon its surface. But this is as we might expect, if the attraction is inversely proportional to the square of the distance, for the distance of the moon from the centre of the earth is 60 times the radius of the earth; and thus, if we divide 193 inches, or the space through which the stone fell in the first second, by the square of 60, namely 3600, we get the 0·0536th of an inch, which is the space through which the moon ought to fall, and does fall, in the same time. This, then, is a strong argument that the same force of gravity acts upon the moon and upon the stone.

On inquiry further, it is found that the earth is deflected from the tangent of her orbit 0·119 of an inch in the second, and hence it follows that the attraction of the sun for the earth must be no less than 354,936 times greater than the attraction which operates at the surface of the earth, if this attraction increases after the same ratio as the distance diminishes. At the surface of the earth a stone gravitates through 193 inches in the first second; at the surface of the sun it would gravitate through 5514 inches. This disproportion is indeed great, but it is not greater than may be supposed to exist if the sun's powers of attraction are in any degree proportionate to his volume—a volume so vast, that (to use Sir John Herschel's illustration) the surface of the sun would extend as much beyond the orbit of the moon as that orbit is beyond the surface of the earth if the centre of the sun was where the centre of the earth is at present. If, indeed, the solar powers of attraction were directly proportionate to the solar volume, they would be four times greater than they are; but, as they are, comparing volume with volume, they are four times less than the powers of terrestrial gravity.

The attraction which acts upon the other planets is inversely proportional to the square of the distance; for on measuring the distance to which they are deflected from the tangents of their orbits in a second, this distance is found to agree very nearly with what we should expect to find if the solar attraction is sufficient to deflect the earth ·119 of an inch in the same time. Thus, in parts of an inch, Mercury is deflected ·792, Venus ·227, Earth ·119, Mars ·051, Jupiter ·0044, Saturn ·0013, Uranus ·000323, and Neptune ·000132.

It is so likewise with the satellites of Jupiter, Saturn, and Uranus; for on taking any one of these, and weighing the attractive powers of the primary by the fall from the tangent of the orbit, and on considering the diminution or augmentation of power which must happen if these powers are inversely proportional to the square of the distance, the spaces through which the companion satellites are found to fall in the same time are in exact accordance with the requirements of the law.

And not only does the sun attract the planet, and the planet its satellite, according to the same law, but the planets attract the sun and the satellites their primaries in the very same manner. It appears, indeed, that every part of the solar system is attracted by every other part with a force which is inversely proportional to the square of the distance. It would be easy to give many illustrations of this great system, but the latest is the most conclusive and triumphant, and we will content ourselves with it,—for if the law can be shown to hold good in such a point, it may be assumed to be true in all points. The illustration is this. The orbit of Uranus presented certain peculiarities, which could not be accounted for by the gravity of the sun and the planets then known. These irregularities were considerable, but they were not allowed to cast any doubt upon the theory of universal gravitation; for it was remembered that the apparent irregularities which had once existed in the orbit of Saturn had been reduced to rule by the discovery of Uranus. Expecting a similar solution, then, astronomers for the most part were content to wait until the telescope should reveal a new planet; but all were not so content. On the contrary, M. Leverier and Mr. Adams addressed themselves to the herculean task of searching through the outskirts of space with no other guide than figures; and month after month, and year after year, each supposing himself to be alone, they plodded along their weary way in silence, until at last M. Gallé received a letter from M. Leverier, in which he was requested to look for a planet in the same plane as the ecliptic, or nearly so, and whose heliocentric longitude at that time was 326°, or thereabouts. This letter arrived at the Royal Observatory at Berlin on the 23rd of September, 1846, and on the night of that very day M. Gallé and M. Encke saw an unknown star of the eighth magnitude in 326° 52′ of this longitude. On the next night this star was found to have moved from its place. It was Neptune. On bringing Mr. Adams' calculations up to the same date, the position assigned to the planet was in the plane of the ecliptic and in 329° 19′ of heliocentric longitude—a difference of only 3° 19′ from the position assigned to it by M. Leverier. The planet was discovered, as we have said, in 326° 52′ of this longitude; and thus the actual position differed only 0° 52′ from the position assigned by M. Leverier, and only 2° 27′ from that determined by Mr. Adams, and only 47′ from the mean of the two calculations. Now those calculations were made upon the assumption that the law of gravitation was universal, and the prophetic result is therefore thought to be a convincing proof of this universality.

The sun, moreover, is considered to be the subject of the same law, for his centre is found to move in an orbit in which the original projection is modified by the united influence of the several bodies which circulate around him. So are the comets, whether these be permanent members or occasional visitants of our system; and so, apparently, are the stars themselves. But at each successive step outwards the difficulties of the demonstration accumulate, from the want of data, from the number of perturbing causes, from the inconceivable vastness of the distance, and so on; but as far as we can go with certainty, so far the evidence is not wanting.

This, then, is the conclusion up to this point—that all bodies and all parts of bodies attract each other with a force which is inversely proportional to the square of the distance. But this is not all. We have already seen that the attractive power of the sun is greater than that of the earth, and this is only one instance out of many of similar differences in this respect. Measured in feet, indeed, a body falls through 16·08 feet in the first second at the Earth, through 8·04 feet at Mercury, through 14·63 feet at Venus, through 8·04 feet at Mars, through 39·40 feet at Jupiter, through 18·00 feet at Saturn, through 12·05 feet at Uranus, through 13·56 feet at Neptune, through 2·72 feet at the Moon, and through 459·47 feet at the Sun. These differences are accounted for by saying that the gravity is directly proportional to the *mass* of the gravitating bodies, and not to their *volume*. Some of these bodies are supposed to contain much less gravitating matter than others, and for this reason they are lighter than others. Indeed, if mass be compared with volume, all the planets, except Mercury, as well as the Sun and Moon, are lighter than the Earth, and some of them much lighter. Taking the Earth as 1, Mercury is 3·45, Venus 0·92, Mars 0·95, Jupiter 0·94, Saturn 0·12, Uranus and Neptune 0·17, the Sun 0·26, and the Moon 0·62. The differences in gravitating power, then, are accounted for by saying that the power is directly proportional to the mass of the gravitating bodies. If the mass were doubled the weight would be doubled; if halved it would be halved; and so on. In the first case a body would fall towards the Earth through twice 16·03 feet in the first second, in the other case it would only fall through 8·01 feet. All this has been determined by experiments, as by those of Cavendish and others.

What, then, is the final conclusion of this magnificent theory? The conclusion is, that every particle in the universe attracts every other particle with a force which is directly proportionate to the mass of the attracting particles, and inversely proportionate to the square of their distance; and that this attractive principle is the sole *force* which is concerned in maintaining the movements of the heavenly bodies.

Now there is no manner of doubt that the heavenly bodies will continue to describe their several orbits if they were originally projected with a given velocity in a tangent to their orbits, and then left to the action of the force of gravity, *if they encounter no resistance in moving.* But is it certain that they do not encounter such resistance? Now, that it is not certain, we may perhaps argue, partly from the retarded movements of Encke's comet, and partly from the previous considerations respecting law. It does not appear possible to account for the retarded movements of Encke's comet, without assuming the presence of some resisting medium in the track along which this body travels—a medium of exceeding rarity, it is true, and one which might only tell in a short time upon bodies like comets, but which must tell somewhat upon the movements of the densest bodies. We know so little about comets, however, that any argument which is derived from their movements alone can be of little weight; and, on the other hand, it may be said that if space be sufficiently empty to allow a comet to move along with comparative freedom, it is to all intents and purposes a vacuum. The other objection, which arises out of the views which have been explained in the foregoing pages—views which discard

Some difficulties which are not altogether explained by the Newtonian philosophy.

The probability that space is not the incorporeal void which is necessary to allow the unimpeded continuance of the motion resulting from original projection.

imponderable agencies, and connect light, heat, and motion with certain material changes—is not so readily set aside. According to these views, the solar light and heat could not travel to the earth without a material track. According to these views, even motion may be said to require a resisting medium for its manifestation. Now this difficulty, as we have said, is not so easily set aside; for though it is not yet proved that the light and heat and motion of the heavenly bodies are analogous to the light and heat and motion of which we have spoken, yet are we obliged by the recognized rules of philosophising to assume the analogy until we know the contrary. In making this assumption, moreover, we are proceeding from the known to the unknown; for nothing whatever is known of the *causes* of the light and heat and motion of the heavenly bodies.

How, then, is this difficulty to be set aside, for assuredly it is a great difficulty to suppose that space is filled with a substance which is sufficiently real and sufficiently ethereal for our purpose—sufficiently real to allow the performance of those definite molecular changes which in one of their aspects we name chemical, and sufficiently ethereal to oppose no resistance to the free continuance of the motion of projection? Are we to suppose that the invisible contents of space have a motion in the same direction, and with the same velocity, as the heavenly bodies themselves; or are we to suppose that the heavenly bodies are moved along, not merely by an initial tangential impulse, but by that ever-acting force which causes the magnet to revolve around the electrical conductor? After what has been said before, these suppositions occur naturally as a means of surmounting the difficulty in question; but they have nothing to do with the Newtonian scheme of motion. They have nothing to do with this scheme, and yet they seem to offer the only means by which the difficulty is to be surmounted.

Now these very suppositions, which have nothing to do with the Newtonian scheme, but which appear to be necessary to explain the actual movement of the heavenly bodies, if space be not that incorporeal void which it is assumed to be, are the very suppositions which may be entertained if the law of which we have already had a glimpse be the true law of nature; and for this additional reason, therefore, we will presume to apply this law to the explanation of what appears to be still unexplained in the movement of the heavenly bodies.*

* Since the manuscript of this book was in the hands of the publisher, the attention of the author has been directed to a work by Dr. George Friedrick Pohl, Professor of Physics in the University of Breslau ("Der Electromagnetismus und die Bewegung der Himmelskörper in ihre gegenseitigen Beziehung dargelegt," Breslau, 1846), in which an attempt is made to explain the movements of the heavenly bodies upon the same principles as those which account for the rotation of the magnet around a conductor. Dr. Pohl adopts the ordinarily received views by which this rotation is referred to the joint operation of a repellent and attractive force, and he neglects to take into consideration several circumstances which are essential to the interpretation of the movement, so that he cannot be said to succeed in his demonstration; but he is unquestionably a man of a most accomplished and philosophical mind, and he deserves all the praise which belongs to him who takes a first step in the right direction.

Application of the law of the laboratory to the explanation of the motions of the earth.

In the first place, then, let us endeavour to follow the movements of the earth, and in order to this let us assume two things which are not very problematical. Let us assume that currents of electricity (we use the term electricity in that wider sense which has been explained before) surround the earth in a direction which is parallel to the plane of the ecliptic; let us assume that similar currents proceed from the sun to the earth and converge upon the part which is nearest to the sun; and we may soon see that the earth must move around the sun, and that she must rotate upon her axis as well as move onwards in her orbit. Nor are these assumptions at all unwarrantable. The first is not unwarrantable, because the manner in which the magnetic needle is found to lie across the plane of the ecliptic may be taken as an almost certain proof that electrical currents travel in this plane. Nor is the second assumption unwarrantable, for we may appeal to the solar ray, which presents all the signs of the current, as evidence, not only that a current flows from the sun, but that it converges to the parts more immediately under the sun. For may not the greater power of the solar rays at noontide be in part at least the consequence of such convergence?

Let E and S be transverse sections of the Earth and Sun in the plane of the ecliptic, and let the arrows represent the currents of which we have just spoken, and it follows from what has been explained already (p. 72), that the mutual reaction of the two sets of currents will give E that movement which we have called subtensial, and that the continual repetition of this movement will carry E around S in a circular orbit, or rather in a polygonal orbit which cannot be distinguished from a circle. The explanation is precisely the same as that which was employed when speaking of the rotation of the magnet around

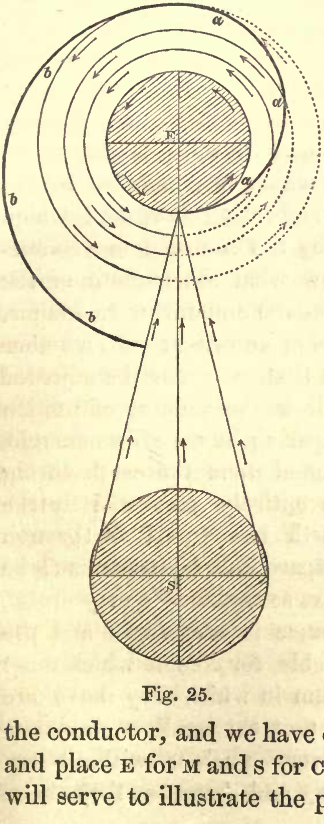


Fig. 25.

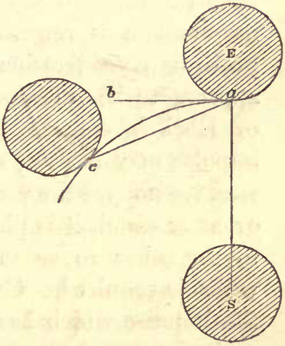


Fig. 26.

the conductor, and we have only to change the letters, and place E for M and S for C, and the former diagrams will serve to illustrate the present object.

The law of the laboratory requires a resisting medium in space.

We may assume, then, without further preamble—for it is not necessary to repeat the explanation already given—that the reactions between the solar and terrestrial currents will cause the earth to move in a *circular* orbit around the sun, if she has to encounter the requisite amount of resistance. If she has to encounter the requisite amount of resistance, we say; for if the ever-acting impulse was not counteracted in this manner, the earth must go on moving with continually increasing velocity away from the skirts of any orbit. In a word, that resisting medium is requisite which is demanded by the previous considerations respecting law, and which appears to be revealed by the retarded movements of Encke's comet. Now what the amount of the impulse may be, and what the amount of resistance, we have not yet the means of knowing; but, whether great or small, it is plain that each must be adjusted to the other so as to allow the amount of motion which is required. Comparing by time, for example, the impulse which has acted upon the earth during a single second must be entirely exhausted by the resistance when the earth has travelled through 101,066 feet, so that no spare velocity remains to be carried over into the next second. We may argue, however, that the resistance is very slight and the impulse comparatively feeble, for comets which must be denser than the medium in which they move are of such exceeding rarity that the smallest star may be seen through their very nucleus without any obscuration of its lustre, and because they have failed to produce any perceptible disturbance in the movements of the satellites of Jupiter when (what has happened more than once) they have fallen foul of them.

How the elliptical orbit of the earth is produced.

But the actual orbit in which the earth moves is an ellipse of slight eccentricity with the sun in one of the foci: and how then are we to account for this? Does the rate of motion vary in different parts of the orbit in consequence of variation in the reactions of the solar and terrestrial currents? This is the question which naturally arises under the circumstances, and the only question which can arise; for it is not possible to conceive of any departure from a circular orbit if the reactions in which the orbital movements originate remain constant.

Now, on considering the surface of the earth, it is not easy to suppose that these reactions are the same in every part of the orbit. If we do this, we at once perceive the very irregular distribution of land and water, for the land is almost entirely confined to the northern hemisphere. Now we know very well how much the actual temperature of a place is dependent upon the neighbouring quantity of land, and how, for this reason, the centre of a continent is hotter than its shores, and the shores than an island in mid-ocean. We know, for example, that it is owing to the comparative absence of land in the southern hemisphere that the circle of ice extends so much further from the southern than from the northern pole. But *heat*, according to the premises, is a sign of the operation of that law which rules the movements of the heavenly bodies, and the simple question now is, whether we are at liberty to use it as such a sign. If we are at liberty—and, after what has been said, reason must be shown why we are not, and not why we are—then the conclusion is, that the reciprocal action between the terrestrial and solar currents is greater when the northern hemisphere is exposed to the light, than when the southern hemisphere is so exposed; and, being greater, it follows that the subtensial impulses will issue in a greater amount of motion, and carry the earth further from the sun when the northern hemisphere is more directly acted upon by the sun; which is really the case. The arrangements of land and water are, indeed, precisely what they ought to be, according to the theory. The lands of the northern hemisphere are more and more exposed to the sun as the sun rises above the vernal equinoxial point, and they are most exposed at the aphelion. The lands of the northern hemisphere are less and less exposed to the sun as he sinks to the autumnal equinoxial point; and at this point, where the sun holds the same relation to the northern hemisphere as it did at the vernal equinoxial point, the distance of the earth from the sun is the same. As the sun sinks towards the winter solstice, he is more and more removed from the lands of the north, and he is most removed at the solstice itself when the earth is at the perihelion; and again, the lands of the north are more and more exposed to the sun as the earth recedes from her perihelion to the point from which we began to trace her movements—the vernal equinox. The positions of the

Earth in her orbit, in short, are precisely what they should be if there are these differences in the reacting powers of land and water which are here supposed; and hence we may assume that the ellipticity of the earth's orbit may depend upon those variations of sol-terrestrial action which are consequent upon the alternate exposure of land and water to the Sun. And certainly there is no reason for supposing that these differences of action are insufficient, for they are far from inconsiderable,—and, considerable or inconsiderable, they cannot be inoperative.

And hence it appears that the peculiar orbital movements of the Earth may, without any undue stretch of fancy, be accounted for on the same principles as those which explain the rotation of a magnet around a conductor.

The law of the laboratory will account for the rotation of the Earth upon her axis.

It appears, moreover, that the very same reactions which produce the orbital movements will also necessitate rotation upon the polar axis, for the direct result of these reactions is to cause preponderating attraction on one side of this axis.

Difficulty of applying these principles to the movements of the planets.

On proceeding to consider the movements of the other planets, we are at once struck with a fact which appears to militate very strongly against the correctness of the previous explanation; and this is the numerical relationship of these movements. If these movements are to be explained in the same manner as the movements of the Earth, it is to be expected that a certain common ratio will be detected in them. It is to be expected that the orbital movement will diminish rapidly as the distance of the planet from the Sun increases, and that the rate of this diminution will, in all probability, be inversely proportional to the square of this distance. Now the planets do move with diminished rapidity as their distance from the Sun increases, but not after the required ratio. Thus, Mercury travels 162,400 feet in a second; Venus 118,800 feet; Mars 81,860 feet; Jupiter 44,297 feet; Saturn 32,715 feet; Uranus 23,070 feet; Neptune 18,435 feet. The motion diminishes as the distance increases, and the diminution is considerable,—but it is not at all according to the required law, for if the motive force underwent no change except that which obliges it to be inversely proportional to the square of the distance, then—taking the motion of Mercury as a standard of comparison—Venus ought to travel 47,072 feet in a second; the Earth 24,421 feet; Mars 10,518 feet; Jupiter 843 feet; Saturn 267 feet; Uranus 66 feet; and Neptune 26 feet. Where, then, is the error? Are we not to explain the movements of the Earth upon the principles which have been laid down, or is there some error in the mode of applying these principles to the movements of the other planets? We can find no error, except it be an error to assume that the same amount of resistance is opposed to the movements of all the planets. This is, indeed, a question; for it is quite possible that the resistance may vary in different parts of space, and that it may become less

How the difficulty just mentioned is to be overcome.

and less as the distance from the Sun increases. Nay, analogy is in favour of this possibility; for it is not unnatural to assume that the arrangement of the atmosphere of the earth may be that of the atmosphere of atmospheres which fills the abyss. And if this be the case, then we see a means of escaping from the difficulty with which we are at present concerned; for if the resistance which the planets have to encounter in their movements is inversely proportionate to their distance from the Sun, it follows that the actual motion of any planet in its orbit cannot be taken as the measure of the force which is concerned in producing that motion. Where the resistance is only slight, a small amount of force may serve to produce an amount of motion which would require a considerable expenditure of force if the resistance were greater; and thus the impulse which would only serve to send Neptune through 26 feet in a second, if he had to overcome the resistance which Mercury has to encounter, may serve to send him through no less than 18,435 feet in a second through the rare medium in which his path is actually appointed.

And thus, if we assume that space is filled with a medium whose powers of resistance are inversely proportionate to the distance from the Sun, the rate at which the planets move is no objection to the idea that these movements may be explained upon the principles which have been employed in explaining the movements of the Earth.

Nor is there any reason why the orbital eccentricity of all the planets should

How the particular orbital eccentricities of the planets are to be accounted for.

not be accounted for in the same manner as the orbital eccentricity of the Earth. At any rate there is no reason why the needful differences of surface may not be assumed to exist in all the planets, and there is some reason to the contrary. Mercury is too much hid in the light of the Sun to allow anything to be known about the nature of his surface; and of Venus nothing is really known except that she is invested with a very dense atmosphere. In Mars the telescope reveals unequivocally well-defined marks upon the surface, which, from their constancy, can only be accounted for by supposing them to be continents and seas: it also reveals fainter and fleeting marks which sometimes obscure the outline of the other marks, and which are properly regarded as clouds. The polar regions of the planet are also seen to be covered with well-defined circular spots of dazzling whiteness, which decrease in size as the summer advances, and which, on that account, are most probably the snows which have accumulated during the long winter. Nothing is known about the surfaces of the planetoids,—and little, if anything, about the surfaces of the large planets beyond the planetoids. The belts of Jupiter are very remarkable and familiar objects, but they are nothing more than markings which indicate the presence of currents in the atmosphere of the planet analogous to the trade-winds of the Earth. They are nothing more than this, because they exhibit changes of form which are inconsistent with the idea that they have any more fixed foundation than heavy clouds. The same may also be said of the markings which are seen upon the body of Saturn; for these are not constant enough to belong to the solid surface of the planet. We see, indeed, the clouds which cover the surface of Jupiter and Saturn, and from these clouds we may infer the presence of water underneath,—and that is all. In a word, we may, without any great improbability, assume that the differences which are met with upon the surface of the Earth are not peculiar to this planet; and we may infer the presence of similar or analogous differences upon the other planets, which differences are so arranged as to give rise to those departures from the purely circular orbits in which the planets would move if there were no such differences. We may infer, for example, that the land, or what is analogous to land, is chiefly confined to one hemisphere, if the eccentricity of the orbit is considerable, as is the case with the orbit of Mercury; and that it is scattered over both hemispheres in corresponding proportions, if the eccentricity is inconsiderable, as is the case with the orbit of Venus. We may, in fact, infer the distribution of the lands and waters, though this be altogether hidden from view, from the eccentricity of the orbit. All this may be assumed; and, to say the least, it is not more difficult to do this, than to assume that the orbital eccentricities of the different planets are due to the different and particular velocity with which the planet was originally projected at a tangent to the orbit.

Nor is there any reason for supposing that the orbital eccentricities of the planets are at all due to differences on the surface of the Sun which are analogous to the differences met with on the surface of the Earth. On the contrary, there is some reason for believing that these differences are not met with upon the Sun; and this reason is in the fact that the perihelia and aphelia of the different planets and comets are related almost indiscriminately to different regions of the Sun, and not to particular regions, as would certainly be the case if the surface of the Sun did present these differences. Indeed, this almost indiscriminate relation of the perihelia and aphelia of the planets and comets to all parts of the Sun, is, according to the premises, a certain proof that the orbital eccentricities of the planets are not due to differences in the surface of the Sun; and, being so, we are compelled to seek for the cause of the orbital eccentricity of each planet in some peculiarity of the planet itself.

And if the orbital movements of the planets are to be explained upon these principles, it follows, as a matter of course, that their rotatory movements must be explained upon the same principles.

All the planets must rotate upon their axes.

Nor is there any reason why the same principles should not apply to the motion of all other heavenly bodies,—comets, satellites, and the Sun himself.

There are two particular difficulties in the movements of comets, but these are not insuperable. The first is the extreme eccentricity of the orbit, the second is the retrograde move-

The law of the laborament of some of the number. It is difficult to account for the extreme eccentricity of the cometary orbits upon the principles which have been laid down. It is difficult to imagine the existence of differences upon the surface of these airy bodies, which, in their reactions with the Sun, can produce such extremely differing amounts of motion; nor is it necessary. Now in accounting for the particular movements of comets, we must take into consideration, first of all, the effects of that resistance which these bodies must necessarily encounter in space, and after this we must weigh the consequences of those remarkable changes of form which they undergo in approaching to and receding from the Sun. It is easy enough to account for the rapid approach to the Sun. The airy comet must encounter greater resistance in its movements than the ponderous planet (for the resistance must increase in proportion as the density of the moving body approaches to that of the medium in which the body moves), and hence it may be assumed that the subtensial impulse which originates in the reactions of the solar and cometary currents may not suffice to send the comet to the distance which is necessary to secure a purely circular orbit. In other words, the excess of resistance to each impulse obliges the comet to stop at a point nearer to the Sun. It may be assumed also that the resistance will act in this way in each succeeding moment, and bring the comet nearer and nearer to the Sun, until the superadded impulse which results from the diminishing distance between the

tory will account for the movements of comets, and explain their peculiarity.

comet and Sun is sufficient to counterbalance the resistance, and carry the comet to the same distance at each succeeding moment, when a movement in a pure circle, or in a polygon of immeasurably small sides which cannot be distinguished from a circle, must commence. It may be assumed also that the *increasing* resistance which the comet *may* meet with in its passage towards the Sun, may have the effect of neutralising for some time the increment of impulse arising from the diminishing distance between the comet and the Sun, and that the increased resistance may cause the comet to approach nearer to the Sun than it would otherwise have done before it begins to enter upon a uniform and circular path. All this is simple enough, but not so the rest. It is easy to bring the comet nearer and nearer to the Sun, until it finds the circle in which the impulse and the resistance are balanced; but it is not easy to carry the comet out of this circle and away from the Sun. How, then, is this? Now the answer to this question appears to be found in the changes in form which the comet has undergone in its passage towards the Sun. In this passage the comet undergoes a remarkable diminution in size. Irregularities in form may accompany this diminution, or they may not, but the diminution is constant. Now there is reason to believe (as we shall have occasion to show more particularly hereafter) that this diminution is owing to the comet having given up, in apparent obedience to the vaporising action of the Sun, one or more of the external layers by which it is invested. In other words, the effect of the change is to expose an inner vaporous coat. What then, we may ask, are the properties of this coat? This is the question. Is it capable of reacting more vigorously with the Sun than the coat which has been vaporised? Does it hold the same relation to this outer coat that land does to water? The assumption is neither impossible nor improbable, for it may be assumed that this inner coat is less rare than the outer coat because it is nearer the centre of the comet, and because it is less rare (inasmuch as the power of reacting is in some sense directly proportional to density) greater reacting powers may be ascribed to it. And if so, then we may understand how the comet may begin to move outwardly from its perihelion, and that this movement may continue for some time with great and scarcely diminishing velocity; for if the increasing resistance in space, as the comet approached the Sun, was sufficient for some time to neutralise the increment of force arising from the diminishing distance between the Sun and comet, the diminishing resistance in space as the comet moves away from the sun may for a long time conceal the loss of force arising from the increasing distance between the Sun and comet, —the smaller amount of force serving to propel the comet to the same distance under the diminished resistance. We may, indeed, without any difficulty, imagine all this to go on until the comet is restored to its original position in the orbit and to its original condition, for as it leaves the Sun it resumes the coating which had been vaporised by the heat of the solar rays. And thus, the great eccentricity in the orbits of comets, instead of being a matter of difficulty, is a matter of necessity. The retrograde movements of some comets, which was mentioned as the second difficulty, may also be disposed of, and with far greater facility. Indeed, all that is necessary is to suppose that the currents surrounding these comets are retrograde,—that is, turned in the opposite direction to the ordinary course; and it must of necessity follow that the reactions between them and the currents impinging upon them from the Sun must issue in retrograde motion.

The law of the laboratory will account for the movement of satellites.

It is with the satellites, also, as with the planets and comets; and these bodies must needs move onwards in their orbits, and rotate upon their axes, if it be assumed, as may well be done upon the premises, that they are surrounded by currents, and that converging currents stream from their primaries upon them. It is clear, also, that those among them which pursue a retrograde course will be made to do this if the currents surrounding them are retrograde as regards the common course.

The law of the laboratory will account for the movements of the Sun.

And if the planets and comets must move in their orbits and rotate upon their axes in consequence of the reactions which take place between the Sun and them, it follows that the Sun himself must circulate and rotate. The Sun himself must do this, because the attracting powers of the currents which proceed from him to the planets and comets are intensified on the side on which the direction of these currents coincides with the direction of the currents surrounding the planets and comets, and diminished on the side on which the direction of the currents is not coincident.

Nor is this all. On the contrary, it is necessary to suppose that every body in the universe acts and re-acts upon every other body in the same manner; and that the result is, not simple attraction in the straight lines which connect these bodies, but attraction so directed as to determine orbital and rotatory movements, such as would result if the re-acting bodies had been set in motion by an independent projection in free space, and then left to the action of the force of gravity.

The attraction of currents is the real force of gravity.

But what of the force of gravity? It has been said that this force cannot be analogous to the attraction of currents of which we have been speaking, because it operates between all bodies indifferently; whereas the attraction of currents is only manifested under peculiar circumstances, and between few bodies. But it is very possible that all bodies may *naturally* be subject to these currents, and that the only peculiarity of iron, and of the few bodies which are akin to iron in this respect, is in the readiness with which these natural currents are given up for artificial currents, or with which the natural currents are rendered evident. And certain it is, that the whole earth is subject to these currents; for there is no place where the magnetic needle does not betray the presence, not only of currents, but of currents which pass in the same direction, and which must therefore cause attraction between the several parts and particles which are subject to them. These several parts and particles, indeed, must needs attract each other if they enter into the course of currents which pass in the same way; and as they do so, and as the law of the attraction is the same as that of gravity, why may not this attraction be the attraction of gravity? And if there is no reason to believe in the existence of any special force of gravity upon the earth, there is assuredly none to be found elsewhere.

Hence the movements of the heavenly bodies are due, one and all, to the law of the laboratory.

In this way, then, it is possible to trace in the regions beyond the Earth the workings of the law which is revealed in manifold operations upon the Earth; and the movements of the heavenly bodies would seem to be obedient to the actions which determine the experimental movements of which we have spoken in a former page. Much, no doubt, remains to be done before these hints can be constructed into a perfect theory, but in the meantime it must be remembered that the explanation which has been offered is based upon the firm ground of experiment and analogy, and that it initiates as well as maintains the rotatory and translatory movements of the heavenly bodies, and this without requiring that space should be that incorporeal void which the imagination is now so sorely taxed to conceive. But we must proceed to the consideration of other phenomena, for it is only when we get a view of the whole subject that we can judge of the full value of the evidence in this or any other particular point.

CHAP. III.

SEARCH AFTER A CENTRAL LAW IN SOME OF THE PHENOMENA OF NATURAL HEAT.

The importance of heat in the economy of nature.

It is not easy to overrate the importance of heat in the economy of inorganic nature. Without heat the skies would be without water, and without water the glorious drapery of clouds would vanish, and the brightness and lustre of the morning would change into gloom and darkness. Without heat the rivers would become motionless glaciers, and the solid sea would no longer palpitate in sympathy with the heavens. Nay, the very air must freeze into adamantine hardness under cold so terrible, and the solid earth must shrink into smaller compass. Nor is this all. On the contrary, there are many smaller but still very important effects of heat which have yet to be traced, and which will enable us to see that heat is something more than an element of second-rate importance in the law of nature.

The amount of heat which the earth is continually receiving from the sun is very great. According to M. Pouillet, the annual amount is sufficient to melt as much ice as would cover the whole surface of the earth to the depth of 185 feet. Of this amount, it is calculated that the sun supplies as much as would melt 100 feet, and the stars the rest. What, then, may we ask, will be the effect of this amazing amount of heat upon the earth? That it must melt ice and convert water into vapour is obvious, but is this the sole effect? Is there no action upon the land? In considering this question we may leave out altogether the effects of sidereal heat, not because these effects are inconsiderable in themselves, but because they do not present those appreciable alternations of action which of necessity belong to the solar heat. In the case of the heat proceeding from the sun, it is evident that all parts of the earth cannot be acted upon at once, and that the differences of action cannot be inconsiderable if the amount of heat be as great as there is reason to believe it to be. In other words, the hemisphere of the earth which is exposed to the light will be affected very differently to that which is in the shadow. But there can be none of these differences in the action of the sidereal heat, because this heat streams equally and constantly upon all sides of the earth at once, and not upon a single hemisphere, as is the case with the solar heat.

The amount of solar heat communicated to the earth. Probable effects of this heat.

In estimating the action of solar heat upon the earth, it is evident that the action upon land will differ from the action upon water. In a hot day, as every bather knows, the land is very much hotter that the water. Nor is this to be wondered at, for the water is converted into vapour almost as fast as the heat is communicated, and in this way a comparatively small amount of heat can penetrate to the great body of water below. The land, on the contrary, absorbs the heat with great readiness, and sometimes to a very great extent. Sir John Herschel tells us that he has observed the temperature of the surface-soil in South Africa as high as 159° Fahrenheit, and he gives a quotation from Captain Sturt's exploration in the interior of Australia, which shows the same fact in a still more striking point of view. "The ground," says Captain Sturt, "was almost a molten surface, and if a match accidentally fell down it immediately ignited."

And if the land absorbs the heat in this manner, what must be the consequence? May we not argue that expansion will be one consequence? Such, undoubtedly, is the inference which naturally arises from several familiar facts, and chiefly from some very valuable experiments which were made in America by Colonel Totten, and reported by Lieut. Bartlett, of the United States Engineers.* In building Fort Adams, it was found impossible to join the coping-stones of the walls in such a way that the joints should be perfectly tight in all weathers. If the stones fitted tightly together in warm weather, they gaped in cold weather, so as to form cracks through which the rain could readily penetrate to the wall below; and with sandstone coping-stones of five feet in length these cracks were wide enough to admit the blade of an ordinary clasp-knife.

* Prof. Silliman's Journal for 1832, vol. xxii. p. 116.

Attention having been thus called to the matter, it was determined to inquire into the influence of heat upon some of the principal stones in ordinary use for building purposes, and with this view portions of granite and marble and red sandstone were submitted to numerous and careful experiments. The measurements were made by means of a white pine rod with copper elbows at the tips, which elbows were made to embrace the ends of the stone under examination, and in every instance due allowance was made for the expansion of the wood and metal; the expansion of the wood being at the rate of ·0000306 of an inch in a foot for every degree of Fahrenheit, and that of the metal ·00011308 of an inch in a foot for every degree of the same scale. The particulars of these experiments are stated in the paper, but it is enough for us to know that for every degree of Fahrenheit a foot of granite expands ·0000579 of an inch, a foot of marble ·000068016 of an inch, and a foot of red sandstone ·000114384 of an inch. These are the results of these experiments, and these are the data upon which we may attempt to form some conception of the degree to which the earth may expand under the action of solar heat—to form some conception, we say, for these data are too uncertain, and the problem is too complicated, to allow us to do more than guess at what may be the degree of expansion under these circumstances.

In order to form some conception of the degree to which the earth may be affected by solar heat, we may assume the case of an imaginary earth of solid granite, and ask what would happen if it expanded after the rate which has been specified. If we ask this question, the answer is that the radius must expand 1209 feet for every degree of Fahrenheit,—an amount which is equal to no less than 2·29 miles for ten degrees of the same scale. Such must be the rate of expansion in such an earth under this trifling elevation of temperature; and, great though it be, it is not half so great as it would be if the imaginary earth were formed of sandstone instead of granite.

The solar heat will cause the earth to expand on the side next the sun.

It does not follow, however, that the actual earth ought to expand at this rate, or in any degree approximating to this rate. In the ideal case, the earth is one unbroken mass of granite; in the actual case, there is much water, and the land is made up of fragments and particles with innumerable interstices. In the ideal case, that is to say, there is nothing to mask the law of expansion, for it is not easy to suppose that this law should be modified by the mere size of the body expanding; but in the actual case there is much to mask the law of expansion. There is much to mask this law, partly because the water which covers so large a portion of the surface will expand into a volatile vapour, and partly because a great part of the expansion of the land must be expended in the filling up of the interstices which separate the fragments and particles of which the land is composed. And thus it is possible to see in these interstices, not so much waste space, but a provision for balancing the expansibility of the earth,—a provision which is precisely similar to that which the engineer has to make in laying down the individual pieces of a railway; and carrying out this idea, it is possible to see a reason why the earth should be principally water or sandy waste where the sun's rays fall the hottest.

Considered in this point of view, then, the wonder is, not that the earth should be expanded by the solar heat, but that it should be expanded to so trifling an extent. How little or how much it is expanded we shall have occasion to consider presently. In the meantime, we must be content to understand that the side of the earth which is exposed to the sun must expand to a greater extent than the side which is away from the sun. We must be content to understand that one effect of the solar heat will be to cause the earth to bulge out towards the sun.

But there is another effect of solar heat which is not less probable or important than the one which has just been considered,—an effect which is consequent upon the *form* of the earth; and in order to understand this we must also have recourse to an imaginary case. Let us suppose, then, that the earth is replaced by a ball of water of equal size and form, and let us ask what will be the effect of the action of solar heat upon it. The effect will be that on the side exposed to the sun a large quantity of water will be converted into vapour, and the probability will be that some of the rays will pass through the water, and, being refracted in their passage, will be condensed into a focus at some little distance beyond the surface on the side away from the sun. This ocean-orb would act, in fact, as a spherical lens. A similar result would also follow if this orb of water were replaced by an orb of rock-salt,—but with this difference, that the focus in which the rays converged would coincide with the surface of the sphere, or else fall within that surface. This difference would be owing to the greater refractive powers of the salt as compared with the water, for the focus must be at the surface, or just within the surface, in all diathermanous spheres whose refractive indices are 2, water being 1·336. If now a substance of still higher refractive powers were substituted for the rock-salt sphere, the focus would be still deeper within the surface most removed from the sun; and if the powers were very high the focus might even be withdrawn to the *centre*. If, for example, an orb of chromate of lead (whose refractive index is 3) were substituted for the sphere of rock-salt, the focus would be very considerably within the surface. Now the diathermanous properties of various bodies vary very considerably. Many bodies are altogether athermanous to artificial heat, but all bodies, so far as we know, are more or less diathermanous to solar heat. Transparency is not at all necessary to diathermanency. Rock-salt, which is the most diathermanous of all known bodies, transmits the heat with equal readiness when its surface is blackened with smoke, and the opacity of obsidian opposes no bar to this transmission. What then? Is the Earth herself permeated by some of the solar rays? Is "nothing hid from the heat thereof?" If it be so—and mere

The solar heat will be brought to a focus within the earth.

size can be no objection — these rays must be brought to a focus at a considerable distance *within* the surface which is most removed from the sun, for the refractive indices of various bodies increase with their density, and the density of the earth is much greater than the density of chromate of lead. Compared with water as 1, the density of the earth indeed is 5·67.

The objections to this view may be set aside.

But, it may perhaps be asked, is there not reason to believe that the heat of the sun does not penetrate into the earth beyond that stratum of invariable temperature where the fluctuations of atmospheric heat cease to be perceptible? Now it is certain that the fluctuations of solar heat which are perceived on the surface of the earth become imperceptible at a very small depth below the surface; but this does not prove that the heat of the sun does not penetrate any further. What are the facts? The facts are, that the diurnal fluctuations do not extend to a greater depth than $3\frac{1}{2}$ feet, and that the wider fluctuations of winter and summer cannot be traced below 100 feet. It is established also that the extreme range of fluctuation becomes less and less the deeper we descend, until at last — that is, at the stratum of invariable temperature — the mean temperature of the surface is maintained without any apparent change. At the depth of 25 feet the range of fluctuation is not more than 2° of Fahrenheit; at 50 feet, 0·2°; at 60 feet, 0·02°. It is established, also, that the length of time which elapses before a part responds to a particular temperature at the surface is directly proportionate to the depth of this part below the surface. At the depth of 25 feet, for example, this interval is full six months, and the result is that the mean temperature of January is manifested in July, and the temperature of July in January. These are the facts, and what is their significancy? Do they show that the heat of the sun is not transmitted beyond a certain very limited depth below the surface of the earth? Assuredly not. On the contrary, the fact that the heat travels so slowly as to be six months in reaching the depth of 25 feet is sufficient to show that it may travel indefinitely further without giving any sign of its presence by fluctuations in its intensity. It is sufficient to show this, for after the end of six months the earth changes its relations to the sun, and the process of giving up heat from the parts deeper than 25 feet must be changed for that of receiving heat, and, *vice versâ*, the process of receiving must be changed for that of giving up.

There are also other and better reasons for supposing that the heat of the sun may and actually does penetrate below the stratum of invariable temperature, and these are to be found in the previous considerations respecting the nature of heat. What is heat? Heat, according to the premises, is a sign of a current travelling under difficulties. If the current be made to pass through a chain consisting of alternate links of thick copper wire and fine platinum wire, the platinum links are alone heated, because they are not fully adequate to the conveyance of the current (see p. 89). According to the premises, indeed, the fact that the heat of the sun is only perceptible at a certain depth below the surface of the earth is no evidence that the ray-currents of the sun do not penetrate beyond this depth, but, on the contrary, it only shows that up to this point these rays encounter certain obstacles to their free transmission. According to the premises, indeed, the fluctuating heat of the superficial strata is only the sign of certain overplus ray-currents which cannot be transmitted in consequence of the deficient conducting powers of the earth.

The solar heat may travel through the earth with extreme rapidity.

Nor does it follow from these facts that the heat is transmitted slowly through the earth. On the contrary, the views which make heat the sign of the current give heat the velocity of the current, and this velocity is to be measured, if measured at all, by the rapidity with which the message flies along the telegraphic wire. Nay, it does not follow that the evidences of heat are transmitted through the superficial strata as slowly as is supposed, for it may be that the more active ray-currents of summer are better able to travel through these superficial strata than the weaker ray-currents of winter, and that, for this reason, there may be less opposition in the strata, and consequently less "heat given out," in July, when the currents are strongest, than in January, when they are weakest. All this is possible, and if so then the fall of the thermometer will simply show that the ray-currents are transmitted more readily than when the thermometer stood at a higher point; and *vice versâ.**

* By thus regarding the phenomenon of heat, it is possible, in some degree, to comprehend the causes of lenticular action. It is

There is no reason, therefore, why the rays of the sun may not penetrate deep into the earth and be

to be supposed that the lines of ray-currents impinging upon the lens are carried through the lens, and through the district beyond the lens, by provoking a continuous line of molecular changes in the glass, and in the atmosphere beyond the glass. It is to be supposed that these ray-currents (in obedience to the law which causes currents passing in the same direction to attract each other) tend to attract each other. It is supposed, also, that this attraction will be of unequal strength in the parts of the current which are passing through the lens, and that the thickness of the lens may be taken as the measure of the strength of this attraction, because there must needs be more active molecules in the line where the lens is thickest. Let the diagram represent a convex lens, and the lines *a b c d e* so many currents. After entering the lens these currents converge, and they do this, we think, because the currents which pass towards the centre exercise a stronger attraction for the currents which pass towards the edge, than is exercised by these outer currents for them. Having a power which is proportionate to its length, the current *c*, that is to say, will cause the currents *b* and *d*, as well as the currents *a* and *e*, to approximate towards it, while at the same time the effect is increased by the movement of *a* and *e* towards *b* and *d*, in consequence of the stronger attracting powers of the latter. The direction of this attraction must also be such as to cause the outer currents to approximate more and more towards the central current, in proportion as they pass from the point at which they enter the glass. It must do this because the currents are fixed in their position, and not able to yield to their mutual attraction, at the points where they enter the glass. This altered direction, moreover, when once acquired, must continue, and thus the convergence must increase more and more as we proceed from the point where it commences, until it ends in a focus of heat and light, if the material substance which corresponds to the focus is inadequate to convey all the currents which are thus made to pass through it. Upon the same principles it is also easy to understand that the position of this focus must move nearer and nearer to the centre of the lens, in pro-

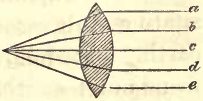


Fig. 27

brought into a focus beyond its centre; and there is an equal want of reason why these rays may not travel with extreme rapidity; and if so, then we may assume two things.

One effect of the transmission of the solar rays will be to cause a permanent bulging out of the equatorial region of the earth.

If the solar rays are brought to a focus deep within the earth, we may assume, in the first place, that the parts corresponding to the focus must be fused; for cornelian, agate, and rock crystal were readily fused in the focus of Parker's great lens—a lens whose diameter was $32\frac{1}{2}$ inches, and whose focal length was 6 feet 8 inches. This fusion, moreover, must be attended with an equivalent degree of expansion, and this expansion must necessitate a bulging out in the overlying parts of the earth. It follows, also, that the position of the focus must continually change as the earth revolves

portion as the attracting powers of the currents which pass through the centre preponderate over those of the currents which pass towards the edge. It is easy to understand, indeed, that the approximation of the focus to the centre must be directly proportionate to the convexity of the lens on the one hand, and, on the other hand, to the attracting power of the individual currents,—for in lenses of different substances the relative power of the individual currents may, or rather must, be different.

And if this be so, it follows that a contrary result must happen when the currents have to pass through a concave lens. Let the diagram represent such a lens, and let the currents *a b c d* and *e* be the currents acted upon by it, and it is at once evident that the event which happened in the last instance must be reversed, and the result be divergence instead of convergence. This must be evident after what has been said, and no further explanation is therefore necessary.

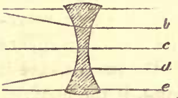


Fig. 28.

upon her axis, and, thus changing, the result must be that the consequent fusion, and expansion, and bulging out, will be carried from the original point in an equatorial belt around the earth to the same point again. And thus we may possibly account for the peculiar form of the earth without the assumption of original fluidity, and for the so-called "central-fire" without the aid of the fire-mist or chemical hypothesis, while at the same time the form of the earth is seen to be intended to answer other purposes besides that of fitting it for easy translation through space. We may assume, moreover, that this equatorial expansion will be constant in the main, for there is no time for the molten mass to cool to any extent before the solar rays are again collected on the same spot. We may assume this, we say, for if the molten mass takes so long to cool when it chances to be ejected as lava from a volcano, how much longer must it retain its heat when it is covered up deep within the bowels of the earth!

Another effect of the transmission of the solar rays will be to cause a transitory bulging out in the region opposite to the sun, which is equal, or nearly equal, to the transitory bulging out which is caused in the region immediately under the sun.

But we cannot assume that this equatorial expansion of the earth is absolutely constant. On the contrary (and this is the second point to which we wished to direct attention) there must be certain fluctuations in this expansion, by which the region immediately over the focus is made to bulge out more than any other part of the equatorial circle. The amount of this fluctuation, moreover, must represent exactly the diurnal and annual variations of the solar heat, and thus the expansion which obtains in the region over the focus must be equal, or nearly equal, to the expansion which is caused in the region diametrically opposite to this, by the direct action of the solar heat (see p. 130), because the heat of the focus is simply the sum of the heat communicated to the earth on the other side.

According to these views, then, the solar heat must produce a very marked and peculiar action upon the earth. It must produce a constant bulging out in the region of the equator, and it must produce a double bulging of a transitory character, of which one part is the exact counterpart of the other,—a bulging in the region immediately underneath the sun, and a bulging in the region diametrically opposite to this. Such is the conclusion to which we are led by these considerations.

But, it may be asked, is this conclusion supported by other than mere abstract considerations? Has it any foundation in sober fact? We think it has, and we think so because it seems to afford the clue to the interpretation of certain great difficulties in the history of the tides and comets, and in the past history of the earth. And first of the tides.

Notwithstanding the immense labour which has been expended upon the interpretation of the *tides*, the subject is still involved in much obscurity. The theory of Newton—that the sun and moon combine to raise the ocean under them into a great tidal wave,

The tides support the idea that the solar heat acts upon the earth in the

and to cause a corresponding wave on the opposite side of the earth by drawing the land beneath the water at that part, and that the moon plays a greater part in this process than the sun, for reasons which will have to be alluded to presently—has long been allowed to be insufficient to account for all the phenomena. Nor is the amendment of Laplace—that the discrepancy between the theory and the facts is mainly owing to the friction of the tidal wave upon the bed of the sea and against the coasts—sufficient to meet the exigencies of the case. Indeed, the simple truth is, that the more we know of the tides the more we are dissatisfied with either theory or amendment.

manner which has been described. Present theory of the tides unsatisfactory.

If the tides be caused in this way, it may be asked, how is it that they are strongest on the coasts of great continents, and feeblest in mid-ocean? The usual height of the tides around the great continents is from ten to twelve feet; whereas at St. Helena it is not more than three feet, and at the majority of the islands in the centre of the Pacific the tides are scarcely perceptible. Indeed, at a comparatively small distance from land, if this land be a small island, we cease to have any evidence of tides. But this is the very reverse of what is required by theory; for according to theory we should expect the highest tides in mid-ocean, where there is more water to raise and where there are fewer impediments to the free motion of the tidal wave.

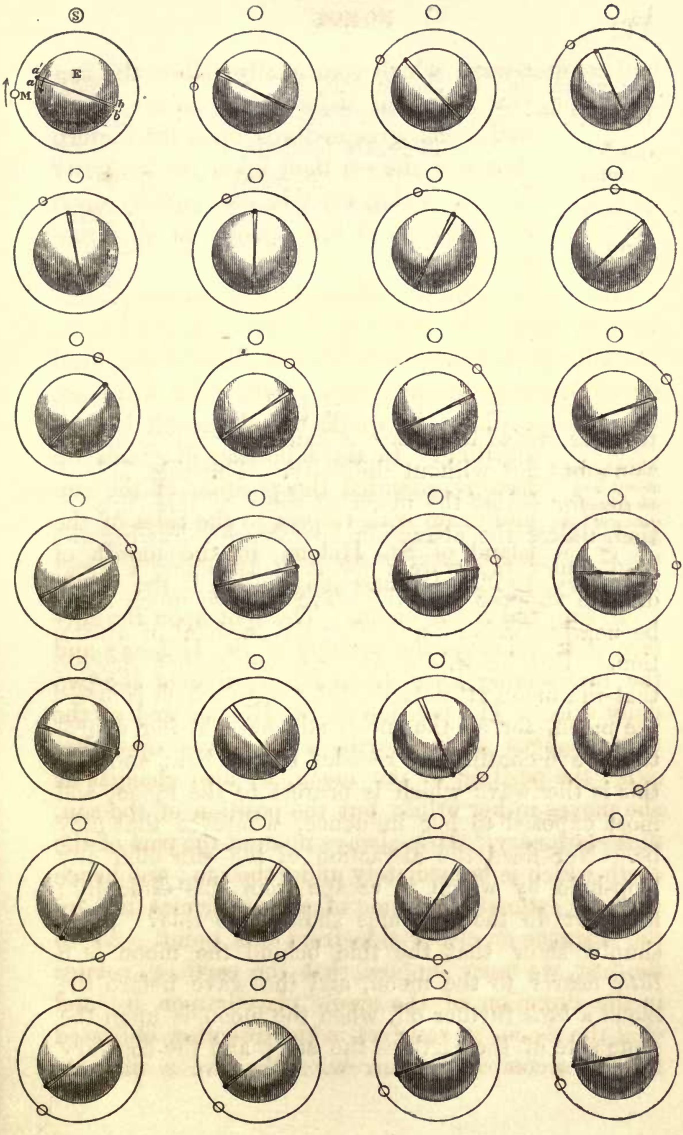
One great objection to the present theory of the tides.

Again, if the tides are caused by a great wave and counter-wave which continually follow the sun and moon, how is it that these waves do not break with much greater force upon the eastern shores of the sea than upon the western? How is it that the tide sets equally upon the coasts, and this equally in all directions?

Another great objection to the present theory of the tides.

Nor is the difficulty diminished when we endeavour to realise the action of the sun and moon upon the tides at an island in mid-ocean, where the local impediments to the free flow of the tidal wave are as few as possible. If we do this the result is most startling. In the following diagrams we have represented the position of the sun and moon with respect to the tides of the island of St. Helena, in the month of February, 1853. In these diagrams E is the earth, S the sun, and M the moon. The spot upon the surface of E indicates the position of St. Helena; and the intersecting lines *a b* and *a′ b′*, that of the two daily tides. The position of St. Helena and of the tides changes as the earth, E, revolves upon her axis; the position of the moon, M, also changes as she moves in her orbit; but the position of the sun, S, is stationary. It is always noon at the part of the earth which is immediately under the sun; and hence we may estimate the time of any particular tide by the distance on either side from this point. As to the rest, we must suppose that the earth, E, rotates in the direction of the arrow placed upon it; and that the moon, M, revolves in the direction indicated by the accompanying arrow. We give a diagram

A third great objection to the present theory of the tides.


S
E
M
a'
a
b
b'

for every day of the month, but we do not repeat the letters; for, after the first, the meaning of each diagram will be sufficiently obvious.

The first glance at these diagrams is sufficient to show that the tides must be referred to lunar rather than to solar influence, whatever that influence may be. They travel around the earth as the moon travels, and very nearly in the same relative position to that luminary. Another glance is sufficient to show that the influence of the moon can scarcely be *attractive* in its character. We may, perhaps, suppose that the *tide behind* the moon is caused by lunar attraction; but not without difficulty. This tide, indeed, is *too far behind* the moon to allow of this supposition, unless the attraction operates by drawing the land under the water; for it is assuming a great deal to suppose that the wave *lags* so much as to be nearly twelve hours after the moment of attraction. But be this as it may, we cannot suppose that the moon attracts the tidal wave which is *before* the moon, for as the moon advances in her course this wave continually recedes before her; and yet this is the wave which is nearest to the moon, and most exposed to her influence, whatever that may be. Nor does the attraction of the sun offer any loop-hole by which to escape from this difficulty; for what do the diagrams show as to this? They simply show that the tide behind the moon is a *little* nearer to the moon, and the wave before the moon a *little* further off, when the moon is upon the same side of the earth as the sun; and the contrary when the sun and moon are on opposite sides of the earth. They show, indeed, that the influence of the sun is similar to that of the moon, only far feebler in degree. It is, indeed, very difficult to look at these diagrams, and suppose that these tides are caused by the attraction of the sun and moon. This is obvious; but it is not so obvious what other conclusion is to be drawn from them. After what has been said, however, the question naturally arises whether the moon may not act upon the earth in the same manner as the sun, and cause a bulging out in the region underlying the moon, and in the region diametrically opposed to this; and whether the tides are caused, not by a change of level in the water, but by a change of level in the land. This is the question which naturally arises under the circumstances.

Another theory of the tides, which obviates the foregoing objections.

In this theory the land immediately under the sun, and the land directly away from the sun, is supposed to rise out of the water in obedience to the expansive action of heat, the water retaining its level.

Now it is obvious that such a theory will not have to contend against the three difficulties which have just been considered. In the first place, it is quite intelligible that the tides should be high on the coasts of great continents, and wanting, or but very feeble, in mid-ocean; for if the land expands in proportion to the extent of surface exposed to the heat, then it may be supposed that the alternate expansions and shrinkings of a continent will be greater than those of an island, and that, consequently, the tides will be greater around a continent than around an island. In the second place, it is equally intelligible that, instead of following the sun and moon, the tidal wave will, *cæteris paribus*, set equally towards every shore; for, according to this view, the tide is nothing more than the agitation of the edge of the ocean which is caused by the alternate rising and sinking of the land, the level of the ocean being always the same. In the third place, the diagrams of the tides at St. Helena become intelligible. It is quite natural, according to this view, that the moon should be in relation to the region *between* the tides. It is also natural that she should be nearer to the tide *before* the moon than to the tide *behind* the moon, and not exactly midway between the two tides: for *time* must be required to produce the necessary expansion of the land; and time—perhaps a longer time—is also necessary to allow this expansion to pass off. In a word, there is an inertia of land as well as of water, which must be taken into consideration. But the great difficulty in the way of this theory is in supposing that the moon is endowed with anything like heating powers. Is she so endowed?

It is an unquestionable fact that the most careful observations have failed to detect any sensible sign of heat in the lunar rays, unless, as Sir John Herschel inclines to think, the general absence of clouds at the time of the full moon may be considered an argument that the moon has a sun-like power of heating the clouds, and so rendering them invisible. But still we are not at liberty to suppose that there is no heat in these rays. We are not at liberty to do this, because the thermometer cannot be allowed to be the sole standard of judgment in such a matter. What — to repeat a former question —is heat? Is it not the sign of that *law* which, according to the premises, is impressed upon all things, and which rules the action of the moon upon the earth as it rules the action of the sun upon the earth? And if it is, then the thermometer is too coarse a test for the more delicate degrees of *heat*, and for these we must rather have recourse to the mile-long galvanometric coil of Du Bois-Reymond, than to the tube of Fahrenheit. According to these views, indeed, the lunar ray can be no more divested of the idea of heat than the solar ray,—and this is one point gained, for if there is any heat in the ray there is in all probability enough for our purpose.

In speaking upon the action of solar heat upon the earth, we assumed the case of an imaginary earth of solid granite, and found that the radius would expand to no less than 1209 feet for every degree of Fahrenheit. And if so, does it not follow that a very small part of a degree may be sufficient to expand the earth to that small extent to which the earth is supposed to rise above the waters in the case of the tides,—a part so small, perhaps, as to be as far beyond the detective capabilities of the mile-long coil, as the capabilities of the coil are beyond those of the common thermometer? There can be no doubt as to this; and if there cannot, then there is no difficulty in supposing that there is enough power in the lunar ray to cause the tidal expansion of the earth.

But how is it that the moon acts more energetically than the sun in producing the tidal expansion

The moon will act upon the earth in the same manner as the sun, and the tidal expansion which she causes will be greater than that of the sun.

of the earth? This is a natural difficulty, but, with Newton's help, it is easily disposed of. There is, no doubt, an amazing difference between the heating powers of the sun and moon, and the whole of this difference may be allowed. It may be allowed that the heating powers of the sun are 200 or even 300 times more powerful than those of the moon, and that the earth would shrink to the dimensions of the moon if the solar heat was withdrawn; and still the *tidal expansion* dependent upon the moon will be greater than that which is dependent upon the sun. This is evident, for the tidal expansion is the measure, not of the whole amount of the expansion, but of certain fluctuations in this expansion, which fluctuations must be far greater in the lunar than in the solar expansion. All this may be shown in the same way as that by which Newton has shown that the moon must *attract* the tidal wave more than the sun. According to the theory of universal gravitation, the tides are caused, not by the whole amount of the attraction of the sun and moon upon the waters, but by the inequality of this attraction on different sides of the earth. If the tides were due to the entire amount of attraction, then the tide of the sun would be much higher than that of the moon; but as they are owing to certain differences of attraction, the tide of the moon is the highest. And this must be so. The attraction diminishes as the distance increases, and therefore the attraction of the sun and moon upon the earth must be greater upon the side which is nearest the sun and moon, than upon the side which is opposite to this. The difference of attraction may also be measured by the proportion which the diameter of the earth bears to the entire distance. Now the distance of the sun from the earth is 12000 diameters of the earth, and consequently the difference of attraction on the two sides of the earth is the 12000th part of the entire amount of attraction; but the distance of the moon from the earth is only 30 diameters of the earth, and consequently the difference of lunar attraction on the two sides of the earth is as great as the 30th part of the whole amount of attraction. It is no wonder, then, that the moon should raise a higher tidal wave than the sun, and if this be the case with *lunar attraction* there appears to be no reason why it may not be assumed to be the case equally with *lunar expansion.*

The whole question, then, turns finally upon the actual proportion which exists between the solar and lunar powers of expansion; and it becomes necessary to enquire what that proportion is. Is this proportion so great that the 30th part of the lunar expansion is greater than the 12000th part of the solar expansion? Now there is reason to believe that the extreme range of solar heat may be 180° of Fahrenheit (the range being from – 60°, which is the lowest point to which the thermometer has fallen in the polar regions, to + 130°, which is the highest point at which the mercury was noticed by MM. Lyon and Ritchie, in the oasis of Mourzouk); and, therefore, if we assume that the lunar ray is as cold as the coldest solar ray, we may suppose that the solar ray is 180 times hotter than the lunar ray. Supposing, then, that the solar ray is 180 times hotter than the lunar ray, the effect will be to raise by so much the value of the part which the sun plays in causing the tidal expansion of the earth; and, therefore, the value of the part which the sun plays in this matter as compared with the value of the part played by the moon will no longer be as $\frac{1}{12000}$ to $\frac{1}{30}$, but as $\frac{180}{12000}$, that is $\frac{1}{66}$, to $\frac{1}{30}$. In other words, the proportion between the lunar and solar tidal expansion will be very nearly that which Newton calculated as existing between the lunar and solar tidal waves.

It is no extravagant stretch of fancy, therefore, to suppose that the moon may expand the earth in the same manner as the sun, and cause the land to bulge out on the side which faces the moon, and on the side diametrically opposite to this, — and that this action, together with the corresponding action of the sun, is the cause of the tides, the land contracting and sinking down at high water, and expanding and rising up at low water. And assuredly such a theory is more in harmony with the facts of the case than the theory which supposes the tide to be a wave raised up by the attraction of the sun and moon.

The metamorphosis of comets supports the idea that the solar heat may act in the manner which has been supposed.

It appears, also, that the same expansive process is exhibited in certain unexplained changes in the form of *comets*, and this is the point we proposed to consider after having discussed the question of the tides.

In order to understand the nature of the extraordinary and rapid changes in form which are so very distinctive of comets, it is necessary to call to remembrance the amazing size and rarity of cometary bodies. Comets, then, are by far the most voluminous as well as the lightest of all bodies with which we have any acquaintance. The head of the great comet of 1811 was considerably more than a million miles in diameter, and the greatest length of the tail was no less than 130,000,000 miles. Usually, however, the diameter of the head is about 100,000 miles, and the length of tail is far less than that specified. But the principal peculiarity of comets is less in their enormous volume than in their astonishing rarity. They are little more than shadows of substance, for stars of the smallest magnitude remain distinctly visible even when covered by their densest portions. The light which would not pass through the most filmy cloud passes through them without any sensible obscuration. "The most unsubstantial clouds which float in the highest regions of the atmosphere, and seem at sunset to be drenched in light, and to glow throughout their whole depth as if in actual ignition, without any shadow or dark side, must be looked upon as dense and massive bodies when compared with the filmy and all but spiritual texture of a comet."* A similar conclusion arises also out of the infinitely small influence which cometary bodies are found to exert upon the movements of the more orderly denizens of the solar system. The comets

The great volume and rarity of comets.

* Herschel's Outlines, p. 344.

themselves are greatly affected by the attraction of the planets, but the planets appear to be absolutely indifferent to the attraction of the comets. More than once a comet has yielded to the attraction of Jupiter, and passed through the special domain of that planet, without producing the smallest appreciable disturbance in the movements of even the smallest of his satellites. Now it is in this extreme rarity of cometary bodies that we may see in part the explanation of those rapid and extensive changes of form which are so distinctive of comets; for if an ordinary cloud may undergo the great metamorphoses which it does undergo in the comparatively dense region of the atmosphere, a comet, which is infinitely more shadowy than the cloud, may be expected to undergo still more marvellous changes in that atmosphere of atmospheres which extends into space.

The changes which pass over the forms of comets are of a very complex nature. As the comet approaches the sun it diminishes in size, as it recedes it enlarges. As it approaches the sun, also, it often puts out a tail-like process from the side which is most removed from the sun, and it is difficult to know whether this tail is more remarkable for the rapidity with which it is formed, or for the distance to which it is carried. Thus, the tail of the great comet of 1680 (the comet observed by Newton), which was 60,000,000 miles in length, was emitted in two days; and the tail of the comet of 1843, which was long enough to have extended from the sun to the orbits of the planetoids, was formed in less than twenty days. The disappearance of the tail is also as rapid and mysterious as the appearance. Sometimes there is more than one tail, and sometimes the tails project from different parts of the body; but there is much obscurity upon this and upon several other matters in connection with the general history of comets; and it is better, therefore, to leave generalities, and speak of the particular changes which were observed in Halley's comet in 1835, for these may be said to be the only particulars which are absolutely authenticated.

Halley's comet, then, long eagerly anticipated, became visible as a small round tail-less nebula with a spot brighter than the rest placed eccentrically within it. On the 2d of October, 1835, the tail began to project from the part most removed from the sun; on the 20th of the same month the tail had reached its greatest length; on the 5th of November it had nearly disappeared. Concurrently with these changes there was an ejection of nebulous matter from the part *nearest* to the sun, and this ejection continued at intervals for several days. On the 8th of November, according to M. Schwabe, a process like a "second tail" pointed towards the sun. At the same time the luminous nucleus underwent changes of form which reflected in some manner the changes of the entire comet, tail-like processes being given out on one side or the other, or on both sides at once, or two processes on one side, and generally in a direction more or less backwards from the sun. The comet made its first appearance after perihelion on the 24th of January, 1836. At this time it was

The changes in Halley's comet in 1835.

visible to the naked eye as a star of the second magnitude, and with the telescope it presented a well-defined and nearly circular head, surrounded with an exceedingly delicate halo or coma, but without a trace of tail. The bright nucleus was like "a miniature comet with a head and tail of its own," and with the tail turned away from the sun. On the 25th and 26th the form continued circular, and the only perceptible change was in the size. The size, indeed, had become greatly increased, but not uniformly, for the halo had gone on diminishing from the first. On the 28th the halo had ceased to be visible. On the 30th there was a great change both in size and form, the size being greatly increased, and the form no longer circular. On the contrary, the form had now become decidedly parabolic, the outline next the sun being distinct and rounded, and that away from the sun confused and shaded off. From this time up to the 23d of February the comet gained rapidly in size without any material change in form. The addition of new substance, however, was not uniform, and day by day it was evident that the comet gained most in the parts away from the sun, precisely as if it was in the process of recovering its lost tail. As these changes went on, the lustre became obscured, and a few days after this time the obscuration became so great that the position of the comet could be no longer recognised. These are the main facts in the history of Halley's comet in the year 1835.

The comet, then, decreased in size as it approached the sun, and increased in size as it receded from the sun; and this is what we may understand, though at first glance we should have been disposed, perhaps, to expect the contrary. It is what we may understand, because a large quantity of the substance of the comet is dissipated in invisible vapour by the increasing heat of the sun as the distance diminishes, and because this vapour is again condensed into visible substance as the comet moves away into colder regions.

Nor is it difficult to account for the ejection of nebulous matter from the side facing the sun at the time when the tail is in process of formation; for it is to be expected that the part nearest to the sun will be most heated and expanded.

The solar heat may cause the ejection of nebulous matter from the side nearest the sun.

It is more difficult to understand the changes in the nucleus and the formation of the tail; but this difficulty is not insuperable, and the same explanation will apparently apply in both cases.

What is this luminous nucleus? It can scarcely be a solid substance in the ordinary sense of the word, for the smallest stars were seen through it without any perceptible diminution of lustre. It can scarcely be more solid than the most ethereal light. What, then, is the luminous nucleus? Is it the focus in which the rays of the sun are made to converge by the lens-like action of the comet? Is it the analogue of the "central fire" which is hid from sight within the bowels of the earth—the "central fire" seen through a transparent

The solar heat may be concentrated at a focus within the comet, and this focus may be the luminous nucleus.

crust? After what has been said already, this is a natural view to take of the matter; but there is one serious objection to it, and this is the fact that the density of the comet is not sufficient to bring the solar rays to a focus *within* the body of the comet. With a body of such rarity, indeed, the position of this focus must be far, very far, *beyond* the surface, for it requires a density as high as that of rock-salt to make the focus coincide with the surface. There is, however, one way of getting over this difficulty, and this is by supposing the comet to be composed of several concentric layers with wide intervening spaces; for in this case each layer, as well as the whole comet, will act as a spherical lens, each with its own focus, and the foci of the innermost layers may be within the outermost layers. This may be seen by a diagram in which the rays proceeding from the sun, S, are refracted by a comet, C, consisting of four sepa-

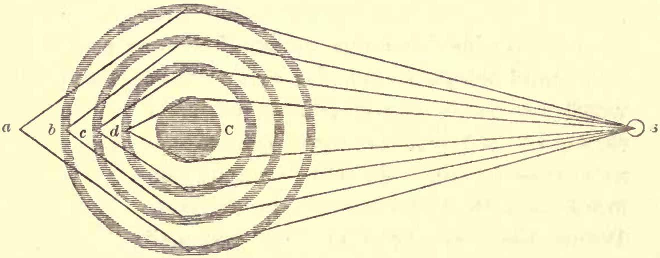


FIG. 30.

rate layers, and brought to a focus at four different points, *a b c* and *d* respectively,—of which points *a* is *beyond* the surface, *b* coincides with the surface, and *c* and *d* are within the surface. In this way, then, it is possible to account for the existence of a luminous eccentric focus within the comet, and also for certain marked changes in the appearance of that focus. If, for example, the focus *d* coincides with a layer of the comet as it does in the diagram, we may very well suppose that the effect will be to convert the part of the layer upon which it impinges into a jet of luminous vapour. We may suppose, moreover, that this jet will pass off in the direction in which it meets with least resistance, and that this direction will not be constant, for as the comet revolves upon its axis new jets will be formed and other paths opened for them. All this is allowable, but is it probable? It is certainly not altogether conjectural, as we shall see presently.

The focus before mentioned may undergo the changes which the nucleus is seen to undergo.

In the same way it is possible to account for the formation of the tail, for all that is necessary is to suppose that the focal action of the sun's rays within the comet is to produce expansion of the parts corresponding to the focus, and that the overlying layer or layers are forced outwards from the side most removed from the sun,—forced outwards in this direction because the position of the focus *must* be nearer to this side than to the side nearest to the sun; and forced outwards to an amazing extent, and with amazing velocity, for the degree to which and the rate at which a body of such extreme rarity as a comet may expand under high degrees of heat, such as must be

The consequence of the focal concentration of the sun's rays within the comet may be to expand the overlying substance of the comet into the tail.

met with in the focus, is up to the very limits of amazement.

Now it is an argument in favour of this explanation, that the nucleus and tail are dependent upon the same cause for their existence, and that this cause is one which operates equally upon the earth. Indeed, it is possible to fancy that the earth itself might be furnished with a tail if the point at which the sun's rays were made to converge was moved so near to the surface as to act powerfully upon that surface and upon the atmosphere above it. Nay, it is possible to fancy that the earth *does* actually present the appearance of a small tail over the crater of a volcano in active operation, for the molten lava must occasion a tremendous upward expansion of the superjacent atmosphere. We think, then, that the possibility of accounting for the presence and changes of the nucleus, and for the formation of the tail, by supposing that the comet is composed of distinct concentric layers with wide intervening spaces, is an argument of some force in favour of the actual existence of these layers and spaces. But this is not the only argument, as we shall see presently.

The remaining metamorphoses of the comet may be accounted for in the same manner.

The diminution in size which the comet undergoes as it approaches the sun, has been accounted for by supposing that a part of its substance has been vaporised by the increasing heat,—and this, no doubt, is the proper explanation. And for the same reason it is possible to understand that the tail should also decrease as the comet approaches the sun. There is no difficulty in this. But there is one point in the issue of this process of diminution which demands our attention, and this is the transformation of the comet from an irregular into a regular form. Before the perihelion the comet is furnished with a formidable tail; after the perihelion, it is a *tail-less rounded* body, surrounded with a delicate halo. All the previous irregularity of form is lost; and how? Is it not by the vaporisation of an external layer or layers which had been raised into irregular forms in the process of vaporisation, and by the consequent exposure of another layer, itself the outermost, perhaps, of several other layers? Is not the very halo a sign either of a distinct concentric layer, or of the more delicate substance which had intervened between the layer which we suppose to have been dissipated, and the layer which now constitutes the outer visible surface? Again, is not the dark stripe which divides the tail longitudinally into two parts a revelation of the hollow space which underlies the layer or layers which have been lifted up to form the tail? Assuredly, this dark stripe is indicative of hollowness, and not of the shadow of the comet, as was once supposed,—for it exists when the tail is turned so much aside as to be out of the shadow of the body of the comet.

It is not upon mere conjecture, therefore, that we rest the existence of that peculiar laminated structure which has been assumed to exist in accounting for the peculiar changes of Halley's comet. On the contrary, there is a foundation of fact which will bear the theory,—a foundation which will appear the more stable the more we are convinced that the comet is ruled by the same law which rules the earth and the companion planets, and that that which appears to mark the irregularity of the comet will appear to be one of the most marked signs of regularity when that law is properly understood.

The changes in Halley's comet after the perihelion are easily disposed of, for if the outermost layers were dissipated into invisible vapour as the comet passed from a colder to a hotter region in moving towards the sun, it is to be expected that these layers will be again deposited as visible substance as it passes from a hotter to a colder region in moving away from the sun. It is to be expected, also, that this deposition of condensing matter should be arranged in the parabolic form which has been described, for that focal action of the sun's rays which had raised the outermost layers *from* the outer side of the comet as this body passed towards its perihelion, will prevent these layers from being redeposited in their proper place until the comet has moved sufficiently far from the sun to allow the focus to be brought as far inwardly as it was before the tail began to be raised.

It is not difficult, then, to account in some measure for the metamorphoses of Halley's comet in 1835; and here we leave the subject, for, so far as we know, what may be said of this comet may be said of all comets.

Such, then, is the view which we are disposed to take of the two subjects which have just been under consideration; and, being so, the conclusion is that the so-called agency of *heat* is a very important agent in the operations of nature. In other words, we are able to deduce from the metamorphoses of comets and from the history of the tides some very conclusive evidence in favour of the belief that the true law of nature is one and the same with that law of which we have spoken so much, and of which *heat* is one of the aspects.

But what of that permanent expansion of the earth which was spoken of as resulting from the lenticular action of the earth? Is there any evidence of such expansion? We think that there is, and that it is to be found in the past history of the earth. We think, moreover, that the examination of this evidence will serve to clear away much that is doubtful and hypothetical in this history, and to show, at the same time, the absolute truth and wisdom of all that is revealed in Holy Scripture upon the subject.

The past history of the earth furnishes other and very remarkable illustrations of the idea that the solar heat may expand the earth in the manner described.

What then, let us ask, was the pristine condition of the earth, and what are the changes which have passed over the earth since its creation? Now there are several answers to these questions, but there is one which is at the same time most familiar and most disregarded, and with this we will begin. It is written:—

"In the beginning God created the heaven and the earth. And the earth was without form and void; and darkness was upon the face of the deep. And the Spirit of God moved upon the face of the waters. And God said, Let there be light; and there was light. And God saw the light that it was good; and God divided the light from the darkness. And God called the light day, and the darkness he called night. And the evening and the morning were the first day.

The original condition of the earth, according to the Scriptures, a shoreless ocean.

"And God said, Let there be a firmament in the midst of the waters, and let it divide the waters from the waters. And God made the firmament, and divided the waters which were under the firmament from the waters which were above the firmament; and it was so. And God called the firmament Heaven; and the evening and the morning were the second day.

"And God said, Let the waters under the heaven be gathered together into one place, and let the dry land appear; and it was so. And God called the dry land earth; and the gathering together of the waters called he seas; and God saw that it was good. * * * And the evening and the morning were the third day.

"And God said, Let there be lights in the firmament of heaven to divide the day from the night; and let them be for signs and for seasons, and for days and for years; and let them be for lights in the firmament of heaven to give light upon the earth: and it was so. And God made two great lights; the greater light to rule the day, and the lesser light to rule the night; he made the stars also. And God set them in the firmament of the heaven to give light upon the earth, and to rule over the day and over the night, and to divide the light from the darkness; and God saw that it was good. And the evening and the morning were the fourth day."

According to this sublime history, then, the earth and heavenly bodies were covered with water at their creation. "In the beginning God created the heavens and the earth. And the earth was without form and void, and darkness was upon the face of the deep. And the Spirit of God moved upon the face of the *waters*." * * * "And God said, Let there be a firmament in the midst of the *waters*, and let it divide the *waters* from the *waters*. And God made the firmament, and divided the *waters* which were under the firmament from the *waters* which were above the firmament; and it was so." * * * "And God called the firmament Heaven." *Waters:* where, then, are these *waters?* Now it is obvious that they cannot all of them be found upon the earth. It cannot be said that the firmament is the dry land between the seas, for the dry land did not appear until the third day; and hence the *waters* spoken of cannot be supposed to be separate seas. Nor is it sufficient to say that the firmament is the atmosphere, and that the waters above it are the clouds; for the firmament, which is called heaven, is afterwards described as the place where the sun and moon and stars are set for signs and for seasons and for days and for years. "And God said, Let there be lights in the firmament of heaven to divide the day from the night; and let them be for signs and for seasons and for days and for years; and let them be for lights in the firmament of heaven, to give light upon the earth: and it was so. And God made two great lights; the greater light to rule the day, and the lesser light to rule the night; he made the stars also. And God set them in the firmament of the heaven to give light upon the earth, and to rule over the day and over the night, and to divide the light from the darkness." The firmament, therefore, is evidently the realm of space, and hence the conclusion appears to be that "the waters above the firmament" are the sun and other heavenly bodies, at that time covered with water as was the earth.

But be this as it may, there is no room for doubt as to what was the condition of the earth at the creation; for up to the third day this was that of a shoreless ocean. Morning twice dawned and night twice fell upon an unbroken waste of waters. On the third day "the waters under the heaven were gathered together into one place, and the dry land appeared." The land is represented as being raised above the waters; and upon this statement we are left to cogitate. Now there is little to guide us in the story; and as we choose we may suppose that the land was raised by miraculous means or by natural causes. If we suppose that the land was raised by miraculous causes, we have nothing more to do; if we suppose it to have been raised by natural causes, then we may follow in imagination the solar and lunar rays as they penetrate

The land may have been raised

through the earth during the first two days, and see them converging into a focus within the interior. We may fancy the fusion and expansion consequent upon this focal action as gradually upheaving the overlying crust of the solid earth, until it begins to raise it above the level of the waters. We may trace this land as it expands into a broad equatorial belt; for as the earth revolves upon her axis each part of the equator must pass in succession over the focus. We may trace this ring as it expands into continents and towers into mountains. All this we may see as the natural consequence of the operation of that agency which we call heat; and because we can do this we are constrained to think that the land was raised out of the waters at the creation by natural rather than by miraculous causes.

out of the waters, and its foundations fixed, by the expansive action of the solar heat.

A similar conclusion may also be drawn from the manner in which the land reappeared after the deluge, as we may see by pondering upon the history of this catastrophe:—

The same expansive action of the solar heat would submerge the land and raise it afterwards in another place, if the position of the earth in sp a changed sufficiently.

"In the 600th year of Noah's life, in the 2nd month, the 17th day of the month, the same day were all the fountains of the great deep broken up, and the windows of heaven were opened. And the rain was upon the earth 40 days and 40 nights. In the self-same day entered Noah, and Shem and Ham and Japhet, the sons of Noah, and Noah's wife, and the wives of the three sons with them, into the ark; they, and every beast after his kind, and all the cattle after their kind, and every creeping thing that creepeth upon the earth after his kind, and every fowl after his kind; every bird of every sort. And they went in unto Noah into the ark, two and two of all flesh wherein is the breath of life. And they that went in, went in male and female of all flesh, as God had commanded him: and the Lord shut him in.

"And the flood was 40 days upon the earth; and the waters increased and bare up the ark, and it was lift up above the earth. And the waters prevailed, and were increased greatly upon the earth; and all the high hills that were under the whole heavens were covered. Fifteen cubits upwards did the waters prevail, and the mountains were covered. And all flesh died that moved upon the earth, both of fowl, and of cattle, and of beast, and of every creeping thing that creepeth upon the earth, and every man: all in whose nostrils was the breath of life, of all that was in the dry land, died. And every living substance was destroyed which was upon the face of the ground, both man, and cattle, and creeping things, and the fowl of heaven; and they were destroyed from the earth; and Noah only remained alive, and they that were with him in the ark. And the waters prevailed upon the earth one hundred and fifty days.

"And God remembered Noah, and every living thing, and all the cattle that was with him in the ark; and God made a wind to pass over the earth, and the waters assuaged. The fountains, also, of the deep and the windows of heaven were stopped, and the rain from heaven was restrained; and the waters returned from off the earth continually; and after the end of one hundred and fifty days the waters were abated. And the ark rested in the 7th month, on the 17th day of the month, upon the mountains of Ararat. And the waters decreased continually until the 10th month; and in the 10th month, on the first day of the month, were the tops of the mountains seen.

"And it came to pass at the end of 40 days, that Noah opened the windows of the ark which he had made. And he sent forth a raven, which went to and fro until the waters were dried up from off the earth. Also, he sent forth a dove from him, to see if the waters were abated from off the face of the ground. But the dove found no rest for the sole of her foot, and she returned unto him into the ark; for the waters were on the face of the whole earth. And then he put forth his hand, and took her, and pulled her in unto him into the ark. And he stayed yet other seven days, and again he sent forth the dove out of the ark; and the dove came to him in the evening; and, lo, in her mouth was an olive-leaf plucked off; so Noah knew that the waters were abated from off the earth. And he stayed yet other seven days, and sent forth the dove, which returned not again to him any more.

"And it came to pass in the 601st year, in the first month, the first day of the month, the waters were dried up from off the earth; and Noah removed the covering of the ark, and looked; and, behold, the face of the ground was dry. And in the second month, in the seven and twentieth day of the month, was the earth dried."

The details of the deluge support the idea that the land was raised in this manner.

How strangely circumstantial is this account! How very strange the catastrophe itself! It is not sudden and appalling, as might be expected if it had been throughout the work of a miracle; but it is slow and orderly, as if it had been carried into effect by natural causes. The rains descend and the floods ascend for forty days and forty nights before the earth is submerged; 150 days pass away before the waters attain the height of 15 cubits above the topmost hills; and 150 days are added to these, before the flood has retired and left the ground in an habitable state. Nearly a whole year is consumed in this awful process. The catastrophe, we repeat, is slow and orderly, as if it had been carried out, not by miraculous interference, but by natural causes *after* such interference. It seems, indeed, as if the submersion and the subsequent renovation of the earth was the *natural consequence* of a miracle, and not the *direct effect* of a miracle—of a miracle such as we may easily imagine to have been carried out. Let us imagine a shifting of the axis of the earth by which the action of the sun and moon was removed from the ancient land to the ancient seas, and, according to the premises, the events will follow which are described in the sacred page. The removal of the action of the sun and moon from the land is to take away that expansive power by which the land is kept above the waters. The removal of this action to the sea is to alter the position of the equatorial bulging of the earth to the bed of the sea, and to "break up the fountains of the great deep" by bringing them to the surface as land. At the same time, the encroachments of the waters upon the land, which are consequent upon the sinking of the land and the rising of the bed of the sea, must be greatly accelerated by the tremendous rains arising from the vaporising action of the sun upon the water of the ocean. And thus "the fountains of the great deep" may have been "broken up," and the "windows of heaven" may have been "opened." The waters, moreover, must have gone on continually encroaching upon the land until the earth was reduced to its primal state of a shoreless ocean. But the earth could not continue in this state. On the contrary, the land must continue to sink, and the bed of the sea to rise, until the land had changed places with the bed of the sea—the bed of the sea becoming as much raised above the water as the ancient land was formerly. It must be so, for the expansive power which now operates to restore the land is the same power which operated to raise the land at the creation. All this is intelligible, but is it probable? It is probable, we think, because these causes must have been in operation, unless the law of nature had been suspended during the eventful year of the deluge, and because it is not possible to believe in miraculous interference where natural causes will suffice. It is not possible to entertain such an opinion without supposing that Infinite Wisdom has decreed something superfluous.

Nor is it a sufficient objection to this view, that the land was raised more quickly at the creation than after the deluge. Forty days and forty nights passed before the land was submerged, and 111 days and nights were added to these before the flood was at its height. The water, moreover, *prevailed* upon the earth for 150 days. The ark grounded upon the top of Ararat about the time when the waters ceased to prevail, but the tops of the mountains were not seen until upwards of two months after this time, and the ark had been stationary for five months before the waters were dried up from the earth. The land appears, therefore, to have been raised with much greater slowness after the deluge than at the creation; but this difference, after all, may not be so great as it appears at first sight. At the deluge the new land did not emerge at once, but in detached spots, where the mountain-tops appeared as islands; and five full months had elapsed before the land was prepared for Noah. And even this land may have been but a small part of the present earth. It is not improbable, therefore, that all the land did not appear on the third day of the creation, and that months, or even years, had to pass away before the mountain-chains of the antediluvian world had towered to their greatest height, and the abysses of the antediluvian seas had sunk to their lowest depth. It is not impossible, also, that a longer time may have been required to bring up the land after the deluge than at the creation, because it had to be brought up from the depth of the sea, whereas at the creation the land may have had to be brought up only from a few feet or even inches below the surface of the waters.

It is not impossible, then, to find some reason for believing that the land was raised out of the water at the creation, and after the deluge by the same action which we now see at work in the tides of the sea and in the metamorphoses of comets, and thus the majesty of physical law becomes more clearly manifested in the light which is reflected from the pages of revelation. All this is not impossible, but it may be objected that this view does not make any provision for those numerous revolutions whose histories are supposed to be written upon the crust of the earth. It is quite possible that the land may have been raised in this manner, but once raised, and it appears to be no longer possible that there should be any marked changes in the relative position of land and water so long as the axis of the earth retained the same relative position to the sun and moon. It seems, indeed, as if nothing less than a miraculous shifting of the axis could produce a general or even important revolution in the earth, and as if, without a miracle, stability, and not revolution, must be the result of law. How, then, are we to surmount this difficulty? Are we to suppose that the earth was the seat of these revolutions in pre-adamite periods, and that the Noachian deluge was only one of many miraculous interferences with the quiet course of the earth's history?

The repeated revolutions of the pre-adamite world form an objection to the previous view, for, once raised, there could be no further change in the relative positions of land and sea without a miraculous change in the relative positions of the sun and earth.

This is a question which is left to the decision of science, for undoubtedly the letter of Scripture may

The idea of repeated revolutions in a preadamite world not unscriptural.

be interpreted so as to suit either the preadamite or the adamite cosmogony. There is nothing in the Hebrew word *bara*, as Dr. Pusey has well shown,* which of necessity signifies creation out of nothing, or creation out of something previously existing. It is a stronger word than *asah*, made, in that *bara* can only be used with reference to God, whereas *asah* may be used with reference to man. Indeed, *bara*, created, *asah*, made, and *yatsar*, formed, are repeatedly used as equivalents by Isaiah and Amos. There is nothing, then, in the word *bara* to signify that at the time spoken of in the first chapter of Genesis the earth was created out of nothing, or out of something previously existing, and therefore the antiquity of the earth must be determined by other evidence than the etymology of the word *bara*. The question, then, is, When was the time which is spoken of as "in the beginning"? Is it a time preceding the six days, or is it the beginning of the first day? Now Dr. Pusey considers, and considers very wisely, that the form of the narrative is an argument that the creative act of the first day begins at the third verse, because we find here for the first time the declaration, "And God said," which ushers in the creative acts of each of the succeeding days; and hence he would argue that the creation spoken of in the first and second verses *may* have been in some undefined period prior to the dawning of the adamic epoch. He also shows that this opinion

* See note in Bridgewater Treatise on Geology, p. 22.

was shared by more than one of the Fathers, and he points out the fact that in some old editions of the English Bible, which are not divided into verses, there is a break at what is now the end of the second verse, and that in the edition of Luther's Bible which was published at Wittenburg in 1557, and which is divided into verses, the figure 1 is placed against what is now reckoned as the third verse of the chapter. Now this, as Dr. Pusey says, "is the sort of confirmation which one wished for, because, though one would shrink from bending the language of God's Book to any other than its obvious meaning, we cannot help fearing lest we might be unconsciously influenced by the floating opinions of our own day; and we therefore turn the more anxiously to those who explained Holy Scripture before these theories existed." The Scriptures are therefore silent, and all we have to do is to ask what is the scientific version of the history of the earth.

The pre-adamite cosmogony.

In asking, then, what is the scientific version of this history, we find some differences of opinion as to the earliest passages, and wonderful unanimity as to the rest. Nearly all are agreed in supposing that the earth was created in times immeasurably antecedent to the first day of the Mosaic record. Nearly all are agreed that the bed of the sea has often changed places with the land, and that these mighty revolutions were caused by the casual penetration of water to the inflamed or inflammable interior of the earth.

Many follow Laplace in saying that the heavenly bodies were formed by the gradual cooling and condensation of portions of a revolving "fire-mist," with which space was once filled, and that these bodies are moving now because they retain the original movement of that portion of the mist from which they sprang. The earth, according to them, retains even now so much of the heat of the parent mist that it is at heart a fiery molten mass. On the other hand, there are some who say that the earth was created as a solid body, and that the internal heat is caused by the oxidization resulting from the admission of water to certain elementary substances which are supposed to be hid in the interior.

Be the original condition of the earth what it may, however, it is agreed that sooner or later there were lands and rivers and seas as there are now, and that the rivers began to rob the land and carry the spoils to the sea as they do at present. There were lands and rivers and seas as there are now, and the general law by which they were governed was the same, but the appearance of the earth in these primæval times was very different to what it is at present. In these primæval times, indeed, there was neither plant nor animal, and the only spoils which were carried to the sea were such as could be robbed from a land which everywhere was bare and inhospitable granite. In this state the earth is supposed to have continued age after age, with no other change but that which was caused by the slow wasting of the land, and the slow deposition of sediment upon the bottom of the sea; and in this state it is supposed to have remained until the time had arrived for the land to change places with the sea. And then begins a new epoch, in which the old changes are repeated in monotonous succession, and

> "The moanings of the homeless sea,
> The sound of waves that swift or slow
> Draw down Œonian hills, and sow
> The dust of continents to be,"

are the only sounds until the air is again startled by the roar of the earthquake which is destined to submerge the land, and raise once more the bed of the sea to the light of day. But the new land is no longer the bare and inhospitable granite which it was at first, though still bare and inhospitable, for it is now another kind of rock,—a rock which has been formed out of the sediment which had accumulated at the bottom of the ancient seas, and which has been formed, in part by the heat and pressure which operated at the time of upheaval, and in part by the drying action of the winds and sunbeams after this time.

At length, after repeated revolutions of this kind, there is a great change, and the hitherto barren and desolate landscape becomes covered with forests of tropical luxuriance. There is a change, indeed, of which the history is plainly and permanently written upon the crust of the earth, for these forests, instead of being destroyed by the waters which eventually overwhelm them, are converted into coal by the rock-making processes which are at work during this period of baptism.

Contemporaneously, also, with the appearance of forests, the air begins to pulsate with the breath of animals, and polypes and shell-fish of various kinds become busied in the construction of coral reefs and beds of shells; and hence other changes in the crust of the earth. Hence the presence of animal remains in the sedimentary rocks, and hence the presence of limestone, for the coral reefs and beds of shells are converted into this substance by the same processes which petrify the ordinary sediment of the sea, and transform the vegetation of a former world into coal. And hence each of these more recent epochs ended, not merely in the formation of simple sedimentary rocks, but in the formation of limestone, and coal, and rocks containing fossil remains. It is in this way that many epochs ended. It was in this way that the epoch ended, after which man made his appearance on the earth; and it is in this way that the present epoch will end when the fulness of time shall come.

Hence each seam of coal must have been a lofty forest of trees upon the surface of the earth, and each limestone stratum must mark the spot where corals and shell-fish once lived and worked; and thus each seam and stratum becomes a proof, not only of past revolutions by which the dry land was made to change places with the bed of the sea, but it shows the extreme length of time which must have been occupied in each revolution, for the length of time must have been extreme if these seams and strata are the remains of plants and animals which have lived and died upon the spot.

In addition to these evidences of extreme antiquity, moreover, some have fancied that they could find evidence of the same kind in the organic remains which are entombed in the crust of the earth.

They saw that these remains evinced a simpler type of organisation the lower they descended in the series of sedimentary rocks, and from this fact they jumped to the conclusion that the higher animals had sprung by progressive development from the lower animals,—a conclusion which implies the extreme antiquity of the earth, for any time shorter than eternity would barely suffice for the completion of such changes. These views, however, have never met with many advocates; and geologists, for the most part, are content to rest their belief in the high antiquity of the earth, and in the frequent revolutions of preadamite times, upon the existence of the coal and lime strata.

Dr. Young's opinions respecting cosmogony.

On the other hand, there is a writer of no mean acquirements as a geologist, but whose writings are little known, who revives the views which were entertained by Woodward in 1695, and who asserts that the sedimentary rocks of the present earth were all formed at the time of the Noachian deluge. This is the late Dr. Young, of Whitby.*

What, then, can be the evidence which admits of such different interpretations as this?

The "fire-mist" theory and the chemical theory not necessary to account for the internal heat of the earth.

In commenting upon these opinions, it is evident that we need not go back to the "nebulous theory," or have recourse to existing chemical changes within the earth, to account for the so-called "central fire;" for, as we have argued elsewhere, this phenomenon may be the natural consequence

* Scriptural Geology, 1836.

of the focal convergence within the earth of the rays which impinge upon the earth. But if we had no other explanation to offer, we must object both to the nebulous and chemical theory. We must object to the nebulous theory because we cannot look upon heat as a separable and independent agency any more than we can look upon light as a separable and independent agency; for, so far as we know, both heat and light are signs of a definite action in a definite machinery, such as suns and stars. We must also object to this theory because we have no evidence that the earth is gradually becoming cooler, as it ought to do according to the theory. On the contrary, we may argue from the fact that the date and vine still continue to flourish in Palestine as they did when the Jews took possession of the country, that the earth has undergone no perceptible change of temperature during the last 3000 years; for, as Arago has pointed out, the date will not ripen its fruit if the mean temperature be lower than 84°, and the grape will not ripen at a higher temperature than 84°. Nor is there any good reason for supposing that the earth has ever become cooler by the giving up of inherent heat. The fossil remains which are dug up in temperate latitudes belong, for the most part, to plants and animals which could only have lived in a tropical climate; and these remains have therefore been thought to show that a tropical heat prevailed in these latitudes during the life of these plants and animals. But Sir Charles Lyell has shown that the necessary difference of temperature may be accounted for by supposing a different arrangement of land and sea at these times. He has shown that a tropical heat would prevail all over the earth if the land was accumulated around the equator, and that the general temperature would sink to a degree of polar severity if all the land was accumulated around the poles; and he thinks that the land may have been chiefly collected about the equator at the time when tropical plants and animals flourished in what are now temperate latitudes,—an opinion which derives some weight from the considerations which have been used to show that the original tendency of the focal action within the earth would be to raise the land around the equator. But, be this as it may, the "nebulous theory" must be objected to as a means of accounting for the "central fire" of the earth. We must also object to the idea that this "central fire" is kindled by the oxidisation of certain unoxidised minerals within the earth, not because the theory is impossible, but because it is unnecessary and without any very probable foundation in fact.

If, then, we must speculate upon the original condition of the earth, there is no reason for supposing that this condition was different from that which is described in the first chapter of Genesis; but it is idle to speculate further upon this matter until we have found the answer to several practical questions of greater importance which yet wait for solution. What is the real age of the earth? Is the earth of incalculable antiquity, or

The original condition of the earth may be that which is described in Genesis.

The earth need not be of any extreme antiquity.

is it not? Has it, or has it not, been the seat of repeated revolutions? These are questions which cannot be put aside, and which ought not to be put aside any longer. And surely there can be no uncertainty in the answers to questions such as these.

The coal-strata, as a rule, may have been formed within a comparatively recent period, because they are formed from *drifts*, and not from forests growing on the spot.

The principal argument in favour of the great antiquity and repeated metamorphoses of the earth is found in the coal-strata. These strata are regarded as the remains of forests which have lived and died on the spot; and, thus considered, it follows that each stratum must have been at the surface of the earth for ages upon ages, — for no shorter time would serve for the growth of such an amazing quantity of vegetable matter; and that, after having been at the surface so long, it must have been submerged under the waters, — for without this the matter of the sedimentary rock which lies above it could not have been deposited. Each stratum is therefore the sign of a revolution which occupied interminable ages in its completion. All this appears to be perfectly plain. If the coal-plants grew where they are found, there can be no doubt as to the conclusion. But is it certain that the coal-plants *grew* where they are found? Surely there can be no difficulty about the answer, and this for more reasons than one. If they *grew* on the spot there must be relics of roots in the lower parts of the stratum, and there must be relics of soil. But as a rule there is neither soil nor root. In one or two isolated instances — as in the "dirt-bed" in the Isle of Portland — there is some trace of soil, but only a trace, for the supposed soil is stratified in conformity with the strata above and below it. In this "dirt-bed" there are also a few upright stumps of trees in an upright position, but these are very few indeed. But in the majority of coal-seams there is not a trace of either soil or root. Again, if the coal-seam be the product of a forest growing on the spot, and compressed into its present form, it may be expected that the coal would split in the direction of the fibres of the trees which formed the seam,—and, as the trees would lie in all directions, that the coal would split without any regularity in all directions; but what is the fact? The fact is, that the coal splits *in the plane of the seam*, just as any slate-seam would do. Again, if the coal-seam be formed from the remains of a forest growing on the spot, it ought to be thicker in some places than in others, according as the circumstances were more or less favourable to growth; but the fact is, that the thickness of the seam is uniform, or nearly so, and that the upper and under surfaces are strictly parallel to the surfaces of the sedimentary strata above and below them. Nor is it easy to find a reason for the extreme thickness of some of the coal-seams on the supposition that these seams are formed by plants growing on the spot, for the soil is exhausted and rendered incapable of furnishing the necessary materials for the growth of plants, even after a comparatively short time. In a word, it is more easy to account for the formation of the coal-strata by supposing them to be fossilised *drifts* of vegetable matter, which had been deposited at the bottom of the ancient lakes and seas in the same way as that in which the matter of the sedimentary rocks was deposited. It is more easy to do this for more reasons than one. If the coal-seams are the product of *drifts*, then it is easy to account for the general absence of roots and soil at their under surface. If they are the product of *drifts*, then they will split in the plane of the seam, for the very same reason as that for which the common sedimentary rock will split in the plane. If the coal-seams are formed from *drifts*, then it follows that their arrangement will be in exact conformity to the arrangement of the other strata, for their formation is dependent upon the same causes. If they are formed from *drifts*, it also follows that they may attain a thickness which is altogether unintelligible on the supposition that their material was furnished by a forest growing on the spot. Nor does the occasional presence of trees, or stumps of trees with the roots downwards, at all militate against this view, for there is no reason why these isolated specimens may not have got into their position in the same way that the "snags" of the Mississippi have got into theirs,—that is, not by growing there, but by floating and then sinking there. Indeed, this is the conclusion which is to be drawn from the appearance of the erect fossil trees which abound in some parts of the coast of the Bay of Fundy, and which are being continually brought to light in large crops upon the face of the cliff as the stone wastes under the destructive action of the high tides of this neighbourhood. This is the conclusion which is to be drawn from these trees, because many of them are without roots, and because some of them are found to terminate, not in the coal-seams, but in clay or shale-seams. Indeed, the whole appearance of these trees is suggestive of the idea that they had been floated into their present position, and that it was the merest accident which determined the kind of deposit in which their lower extremities would have to rest. Still it is quite possible, nay probable, that some few of the coal-seams were formed from forests which grew on the spot, for the history of many peat-mosses supports such a conclusion; but as a rule there appears to be no other alternative than to suppose that these strata, like the sedimentary rocks, are the product of *drifts.*

The limestone-strata, as a rule, may be formed within a comparatively recent period, because they are formed from *drifts,* and not from animals living on the spot.

Nor is there any sufficient reason for supposing that the limestone-strata are the work of zoophytes or other calciferous creatures which lived on the spot, except in some very occasional instances. "It requires," says Dr. Young, "the creative powers of fancy to discover in these strata anything like groves or beds of coral, such as exist in recent coral-reefs. The corals of the oolite are generally laid flat, like the shells with which they are mixed, and those which are found in an upright position might acquire that position in the same way as the vertical plants and trees in the carboniferous strata."* Moreover, some of these calcareous strata are evidently formed from *drifts.* "In the marlstone bands occurring in the lias of Yorkshire," con-

* Op. cit. p. 16.

tinues Dr. Young, "there is a seam composed chiefly of oyster-shells, about four or five inches thick, extending for many miles along the coast, being present wherever the marlstone beds appear, and reaching far into the interior, where it is seen in the front of the Cleveland Hills. The shells in this seam are chiefly single valves, and many of them are water-worn, and all of them appear to have floated into their present position, for the shells must have drifted together to form this singular and extensive stratum."* Indeed, it is infinitely more easy to account for the formation of the limestone-strata by supposing them to be *drifts* of detached corals, shell-fish, and various bony remains, than by supposing them to be the workmanship of any animals which lived on the spot; for then the exact conformity in the arrangement of these strata with regard to other strata is accounted for, as well as the absence of the irregularities and other peculiarities of coral-reefs and oyster-beds. Nay, it is even easier to account for the presence of the calcareous remains of the higher animals which are found in alluvial deposits, as in the cave at Kirkdale and elsewhere, by *drifts* than by any other theory. In all these so-called dens, the bones of *many* beasts of prey are found together, in company with the bones of other animals. The bones of the hyæna preponderate at Kirkdale, and those of the bear at Gailenreuth; but along with these are the bones of lions and tigers and other carnivorous animals. How, then, without a miracle, could the animals to which these bones

* Op. cit. p. 15.

belonged have *lived* together? And surely it is more probable that the caves in which the bones are found are *graves* rather than *dens*, and that dead animals had drifted there during an inundation.

Other stratified rocks, as a rule, are formed from *drifts*.

Of the other strata it is not necessary to speak, for they are universally allowed to be *drifts*. There is no difference of opinion upon this point.

These strata may therefore have been formed in one epoch, for if the coal and limestone seams are the product of drifts, the one may have been deposited orderly upon the other in the same basin, and there is no necessity that each coal stratum or limestone-stratum should represent what was once a living growing surface of the earth or sea.

So far, then, there is reason to believe that the several strata agree in being sedimentary in their character. They are all the product of *drifts*, and their only difference is in the material drifted. Hence there is no necessity for alternate elevations and depressions of the land to account for the formation of the coal and limestone strata; for stratum after stratum might be deposited at the bottom of the same sea, successively or alternately with other strata, according as the current brought sedimentary matter from the same or from different regions; and the accumulating rocks may never have been raised above the waters until their whole series was complete. This is evident. How is it, then? Were there many alternate elevations and depressions during the process of stratification, or were there not? And surely this is a question which may be answered with certainty.

Now if one thing is evident, it is that the individual strata must be distorted and broken if they

Evidence that these strata were formed in one epoch.

had been subject to alternate elevations and depressions during the process of stratification. It must be so; for it is not possible that a stratum should have been elevated for many feet, and perhaps for miles, and then lowered to the same extent, and this repeatedly, and yet be in the same uninjured state as it was in before the operation of the upheaving force. On the other hand, it is equally evident that there cannot have been many alternate elevations and depressions during the process of stratification if the different strata are conformable to the same plan. And this is what we do find; indeed, the orderly parallelism and perfect conformity of the strata is one of the most remarkable and obvious phenomena which is exhibited in any section of the earth. The *whole series* of strata is bent and fractured in a thousand different ways, and the displacements are often so great that it is difficult to find the corresponding half of a fractured portion; but there are no special bendings and fractures and displacements in individual strata, and therefore we should be disposed to argue, from the actual appearances of the strata, not only that they were deposited as drifts, but that the process of stratification was not interrupted by the recurring earthquakes which play so important a part in the preadamite cosmogony. In other words, we should be disposed to argue that the process of stratification was completed in one epoch, rather than in many.

And if the several strata were formed in one epoch, and not in many, when did this epoch begin?

Was this beginning within historic times, or was it not? We find the answer, as it seems, in the organic remains which lie entombed within the strata; and the answer is by no means equivocal. The existence of any remains at all may indeed be taken as a certain proof that this entombment was accomplished with a certain degree of rapidity; for if the entombment had been deferred, all traces of them must have soon disappeared under the destructive action of air and water, or under the attacks of those creatures which are commissioned to rid the earth of decomposing organic matters. The very existence of organic remains, we repeat, is an argument of the rapid entombment of these remains. And if so, what must we say of the more perfect of these remains? What of those ferns whose fronds are cast so accurately in the coal-measures that every spore-case is copied? What of those insects whose wings retain every nervure, and whose eyes have lost none of their many eyelets? And what of the cuttle-fish, whose ink-bags have furnished the ink with which the artist has copied them? All these must have been buried before the finger of decay had time to touch them. Nay, some of the animals whose remains are preserved appear to have been buried in the very act of gorging their prey—as in the case of the fish in the Museum at Naples which has another fish in its throat; and others appear to have been overwhelmed rather than buried, so broken and crushed are their remains.

The organic remains entombed in the strata show that the process of stratification must have been comparatively rapid, for, if otherwise, these remains must have been removed by decay.

Nearly all the skeletons of the large reptiles are in this case. Nor is it at all surprising that animals should have been buried quick in ancient times; for the same accident still befals the alligators and other large animals which frequent the mouths of great rivers, such as the Ganges. Indeed, the same accident may even happen on our own quiet coast. Thus, about fifty years ago a narwhal was buried quick in the mud on the coast of Lincolnshire, with only the head protruding. He was seen by a fisherman in this state, and supposed to be dead; but he began to bestir himself when an attempt was made to pull out his horn. In a word, the existence of organic remains at all, and particularly the very perfect or crushed condition of some of these remains, can only be accounted for, as it seems, by assuming a certain degree of rapidity of stratification of the rocks in which they are deposited; and this is the only deduction which can fairly be made. In the face of these remains, indeed, it seems to be impossible to believe that the stratum containing them was so many ages in forming. Long intervals may have elapsed between the deposition of the different strata; but the individual strata must have been formed with rapidity, or the organic remains which are preserved in them must have perished.

But if there were no organic remains it would not be at all certain that the strata had not been deposited with considerable rapidity. On the contrary, we might, if we would, argue in favour of a rapid deposition from the rate

Evidence, apart from the organic remains, that at which the Ganges at present contributes to the formation of new sedimentary rocks. This rate was very carefully determined by Mr. Everest in 1832,* and his conclusion was that the river carried down to the sea annually no less than 6368077440 feet of dried sand —a mass equal in weight and bulk to 42 of the great pyramids of Egypt, and not very far inferior to the amount of lava which flowed from the volcanoes of Iceland during the great eruption which happened towards the end of the last century,—and yet the amount of this lava was so great, that all the nations of the earth might toil for thousands of years before they could quarry it away. So great, indeed, is the quantity of sediment which is brought down by the Ganges during the rainy season, that the sea is rendered turbid by it for 60 miles from the shore. Nor is it certain that the lime-strata were formed with remarkable slowness, for—to cite one illustration out of many—the rate of deposition from some calcareous springs is very rapid. Thus, the waters at the baths of San Fillipe are found to deposit travertin and crystals of sulphate of lime to the depth of a foot in four months. Facts such as these (and many might be cited) serve to show that the sedimentary rocks might have been formed with considerable rapidity, and, in doing this, they corroborate the impression which is gathered from a sight of the fossils. But the testimony of the fossils requires no corroboration, and this testimony is, that the strata in which

the process of stratification may have been comparatively rapid.

* Lyell's Elements of Geology, p. 269.

the fossils are entombed *must* have been deposited with considerable rapidity.

When, then, to repeat the question, did the epoch of stratification begin? Did it begin before the dawn of historic times, or did it not? Dr. Young agrees with Woodward in supposing that the sedimentary rocks were formed at the Noachian deluge by the matters washed down from the antediluvian continents into the antediluvian seas, and that we are now living upon the bed of these ancient seas with this additional covering from the ancient lands; and he uses many of the preceding arguments to establish this opinion. Hence every stratum is to him a sign of the deluge. But this is going to the opposite extreme. Eternal ages may not be necessary, but a few days can scarcely be enough. Besides, the very orderly disposition of the earlier strata is an objection to this view, for everything indicates a greater quiet than is consistent with the turmoil of the commencing deluge. But there is no need that we should limit the process of stratification to the short period of the deluge, and, on the other hand, there is no reason why we should not return to an older doctrine than Woodward's, and agree with Hooke in supposing that the sedimentary rocks were deposited *in the interval between the creation and the deluge.*

In Dr. Young's opinion, the few months of the deluge would allow sufficient time for the whole process of stratification.

The opinion of Woodward that the process of stratification extended from the creation to the deluge more probable than that of Dr. Young.

And thus we return to the point from which we started. It was argued that the causes which determined the elevation of the land above the waters were such as to ensure the *stability* of the land when raised, and that it was difficult to imagine the possibility of any great revolution in the earth without some miraculous interference with the law of nature. It seemed to be literally true that "the bounds of the sea had been established by a perpetual decree, so that they could not be passed;" and for the same reason it ceased to be possible to believe in those mighty revolutions which form a part of the scheme of preadamite geology, without believing in a miracle for each revolution. This scheme required continual revolutions, and, requiring these, it opposed the admission of a law which ensured stability. And what is the fact? The fact is, that geology does not require these revolutions, and, not requiring them, it ceases to be an objection to the admission of the law. Geology, indeed, becomes a witness to the stability of law. In a word, there appears to be no reason why we should believe that the earth was created before the days of Adam, or that it has been the scene of more revolutions than that mighty one which is recorded in Scripture; while at the same time the application of the law which is deduced

No evidence that the process of stratification began before the Adamic epoch.

Hence geology appears to speak of no mighty revolutions except the one which destroyed the antediluvian world.

Hence geology affords no objection to the deduction from theory that the land and sea must remain in the same relative position so long as the earth retains the same relative position in space.

Hence the deductions of science harmonise with and explain the teachings of Scripture, and the deductions and teachings are in perfect keeping with the facts of geology.

from the premises to the interpretation of the letter of Scripture, elicits a meaning which is infinitely deeper than anything which could have been derived from the lore of Egypt.

Natural heat may be referred to the law, named provisionally the law of the laboratory.

And if heat may be considered an important element in the idea of the law of nature, inasmuch as it affords the explanation to several unexplained natural phenomena, what is the inference? Is natural heat an accidental accompaniment of the law of nature, or is it an essential part in the idea of this law? Does it hold the same relation to this idea that artificial heat does to the law of the laboratory? This, we may answer, is the natural conclusion so far as the heat of the sun is concerned, for here the heat is associated with light, chemical action, and other kindred phenomena, just as it is in the law of the laboratory. Nor is this conclusion contradicted by the apparent absence of heat in the lunar rays, for the considerations which have been advanced on the subject of the tides are sufficient to show that heat may not be absent from these rays, but only hidden in them.

The law of the laboratory affords the only explanation of natural heat.

Natural heat may be taken as another

And there is one great advantage, apart from that of simplification, which arises out of this conclusion, and which must also be allowed to be an important argument in favour of this conclusion, and this is the explanation which is afforded of the heat of the sun and other heavenly bodies; for if the law of the laboratory is none other than the law of nature, then, under certain circumstances, heat becomes a necessary effect of law. As we said before, it is law attested by a particular class of nerves. Nay, it is even possible to find some reason why the rays of the sun are attended with sensible heat, and not the rays of the moon. We have already said that the degree of heat connected with electrical currents is directly proportionate to the inadequacy of the conductor. An ordinary current may be passed through a thick wire without producing any evident sign of heat, but, if it is passed from this wire into a thin wire, the thin wire immediately becomes heated; and, on the contrary, the current which heated a thin wire will lose all signs of heat when it is passed from this wire into a thick wire. Is it possible, then, that these facts should have any bearing upon the question under consideration? Is it possible that the sun's rays should feel hot because they proceed from a larger to a smaller body? Is it possible that the moon's rays should fail to produce any impression of heat because they proceed from a small to a larger body?

argument that the law of the laboratory is the law of nature.

A possible reason why there is evident heat in the rays of the sun, and none in the rays of the moon.

CHAP. IV.

SEARCH AFTER A CENTRAL LAW IN THE PHENOMENA OF NATURAL LIGHT.

Natural light may be referred to the law, named provisionally the law of the laboratory.

THE light of the sun agrees with the light which attests the operation of the law of the laboratory, in that it is attended by the same companion phenomena of heat, chemical action, and the rest; and hence we may fairly take the light of the sun as another argument that the law of the laboratory is none other than the law of nature. Nor is it an objection to this conclusion, that the light of the moon and stars is not attended by all the companion phenomena which attend upon the light of the sun. These companion phenomena are not all present, it is true, but their apparent absence may be accounted for in the same way as that in which we account for the apparent absence of heat in the lunar ray. And yet they are not all absent, for a power of motion is mixed up with the lunar and stellar light, and the stellar rays are not devoid of heat.

There is also a great advantage in the conclusion that natural light is another argument in favour of the idea that the law of the laboratory is the law of nature, and this is, that the law of the laboratory affords an intelligible answer to the question, What is light? It affords an answer to this question, for, according to this view, light is nothing more than law attested by the eye. And this answer is surely as intelligible as that which refers light to undulations of inconceivable rapidity, set up we know not how, in an hypothetical ether, which is at once matter and no matter, everywhere and nowhere.

The law of the laboratory affords the only explanation of natural light.

Natural light may be taken as another argument that the law of nature is the law of the laboratory.

It seems, moreover, that we may find in the pages of Scripture a recognition of the dependence of light upon the same cause as motion. At the beginning it was as it is now. The light was no diffused and independent agency, for then, as now, the light was divided from the darkness, and morning followed evening in the same order. Then, as now, the light was divided from the darkness, and morning followed evening, because the earth revolved upon her axis before the sun. Then, as now, day followed day, so that the earth moved along her orbit as well as upon her axis. In a word, light was associated with motion, and hence, arguing backwards, we may suppose that light was associated with the same cause as motion.

The Scriptural account of the creation appears to show that light and motion are bound up in a common cause, as they are in the law of the laboratory.

But there is another point in this account which bears upon a question treated of in the last chapter, and which seems to fix the time of the creation at the beginning of the first day of the Mosaic chronology. At the be-

A collateral inference that the creation of the earth was not far antecedent to the creation of Adam.

ginning the earth was without form and void, and *darkness* was upon the face of the deep. There was no *light* before the first day. And if there was no light, does it not follow that there could have been no motion, no heat, no chemical action? Such, indeed, is the conclusion which must be drawn from the premises; and so strong is the conviction upon which it is founded, that we cannot conceive it possible that the heavenly bodies should have begun to move until the fiat had been given, Let there be light.

But be this as it may, there is no question that *light* is involved in the idea of natural law, and that the fact of its presence may be regarded as another argument that the law which rules in nature is the law which is revealed to us in the experiments of the laboratory.

CHAP. V.

SEARCH AFTER A CENTRAL LAW IN NATURAL CHEMICAL CHANGES.

Natural chemical actions may be referred to the law named provisionally the law of the laboratory.

AFTER what has been said in the previous chapter, little need be said in this chapter and the next.

This law affords the only explanation of these actions.

These actions may be taken as another argument that the law of the laboratory is the law of nature.

What of the chemical properties of the solar rays? Must we not regard their presence as another argument in favour of unity of law? And is not their presence accounted for by unity of law? There is only one answer to this question, and this, as it seems, is in the affirmative.

CHAP. VI.

SEARCH AFTER A CENTRAL LAW IN NATURAL "MAGNETISM" AND ELECTRICITY.

Natural magnetism and electricity may be referred to the law of the laboratory.

This law affords the only explanation of these phenomena.

These phenomena may be taken as another argument that this law is the law of nature.

WHAT of natural magnetism and electricity? Must we not regard the presence of these actions as another argument in favour of unity of law? And may we not account for these actions by unity of law? There is only one answer after what has been said in the previous pages, and this is still in the affirmative.

CONCLUSION.

The object of this work, then, has been to prove that the world of inorganic nature is ruled by one physical law, and not by several physical laws.

It has been shown, first of all, that the phenomena of electricity, magnetism, light, heat, chemical action, and motion, which are developed experimentally, are not to be understood unless they be regarded as signs of one and the same action in ordinary matter. In doing this (among other consequences of the argument) it has been found that we may dispense with the idea of a repellent force in explaining electro-magnetic rotation,—that we may find a physical explanation for the so-called repulsive power of heat, and for the retention of magnetism by the loadstone and steel,—and that we may discover additional reasons for discarding imponderable agents from the interpretation of physical phenomena.

Evidence was then adduced for believing that it is not possible to understand the phenomena of electricity, magnetism, light, heat, chemical action, and motion, which are naturally displayed in the world around us, unless they be regarded as signs of the action of the same central law. In this part of the argument:—

It has been shown that the heavenly bodies will move forwards or backwards in orbits of various eccentricity, and rotate upon their axes, if they are subject to this law, and that they will begin as well as continue to move in this manner.

It has been shown that the tides and the metamorphoses of comets are not to be understood unless we admit the operation of a law of which heat is one of the signs,—that the land may have been raised out of the water, and established upon permanent foundations, by the causes which produce the tides and determine the metamorphoses of comets,—and that these considerations involve great changes in the geological doctrines at present in vogue, which changes are justified by the geological evidence itself.

It has been shown that the phenomena of natural light, and chemical action, and electricity, and magnetism, are only intelligible when they are regarded as signs of the same central law.

It has been shown, in short, that the inorganic world is ruled by one single law, of whose operation the phenomena of electricity, magnetism, light, heat, chemical action, and motion, are only so many signs, —the law, that is to say, which was named provisionally the law of the laboratory,—and that no secret in the world of inorganic nature can be fully understood except upon this assumption.

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