charides. Hudson's rule then permitted him to elucidate the alpha and beta structure of di- and trisaccharides, a problem which previously could be solved only with much difficulty.

Then came the rule correlating the structure of lactones with their optical properties. This rule subsequently played an important part in determining the ring structure of glucosides.

Then came the amide rule of rotation which permitted the correlation of the structure of hydroxy-acids and sugar acids, and as by-products of his theoretical work are many discoveries of new forms of isomerisms and of rearrangements.

It is a rare occurrence that a single principle has led to so many discoveries. All sugar chemists of to-day have been assisted in their work on more than one occasion by the rules which are known as Hudson's rules.

MICHAEL FARADAY. II[1]

By Dr. W. F. G. SWANN
BARTOL RESEARCH FOUNDATION

IN the fall of 1831 Faraday began the first section of his great work, "Experimental Researches in Electricity," the work which he continued for some twenty-three years. These researches appear from time to time as papers transmitted to the Royal Society and they were subsequently put together in a single set of three volumes. They give a most detailed description of his thoughts and work. Experiments are described in the minutest detail. Every paragraph is numbered consecutively from beginning to end, and cross references are added to serve as connecting links between the various researches. His first experiments are on the induction of electric currents. Following the general notions evolving from the known facts that charged bodies induce electrical charges in others in their vicinity, he inquires whether any such phenomena can occur in the case of electric currents. Such problems as these present themselves to him. Suppose we have a wire in which a current is flowing, do we alter in any way the magnitude of that current by bringing into its vicinity another wire carrying a current? The kind of effect he is looking for is one where there will be some permanent alteration or at least an alteration which will persist for the whole of the time that current No. 2 is brought into the vicinity of current No. 1. He makes tests in all sorts of different ways and is finally led to the now well-known result that the induced current occurs only at the moment of change of the other current or during the periods of motion of the circuit carrying that current. Nevertheless, the nature of these phenomena is such as to cause his mind to lay hold of the idea that the various circuits which are involved are not actually ignorant of each other's presence. He thinks of them as being conscious of that presence in sort of a silent way. He thinks of them as being in what he calls an electrotonic state. His mind lays hold of the thought that it is in the change of that state that the current manifests itself. In order to appreciate the whole significance of his attitude in this matter, we must transport ourselves to a state of mind where we do not have the pictures of lines of force which we enjoy to-day. All that came later as an extension by Faraday himself of the ideas which he formulated in the early history of the subject. We have before us simply a set of wires all apparently unconscious of each other's presence. Yet any one of them has the power to know if any change is made in the other. It is one of the characteristic features of Faraday's way of thinking that he seemed to have the faculty of arriving at the essential elements which matter in a qualitative form long before he was able to place that exact significance to them which is associated with quantitative relationships. The quantity which was associated with the electrotonic state appeared in the hands of Clerk Maxwell as the electromagnetic momentum associated with the circuit. Or in terms of more intuitive concepts it refers to the product of the current and the total flux of magnetic induction through the circuit. It is this quantity, a purely mathematical quantity having no physical significance in the ordinary sense of the word, which Faraday succeeded in ferreting out of his experiments as the quantity essential for the coordination of his results. Speaking of this electrotonic state, as visualized by Faraday, the great Clerk Maxwell writes:

> By a course of experiment, guided by intense application of thought, but without the aid of mathematical calculations, he (Faraday) was led to recognize the existence of something which we now know to be a mathematical quantity, and which may even be called the fundamental quantity in the theory of electromagnetism. But as he was led up to this conception by a purely experimental path, he ascribed to it a physical existence, and supposed it to be a peculiar condition of matter, though he was ready to abandon this theory as soon as he could explain the phenomena by any more familiar forms of thought. Other investigators were

[1] An address given on February 14, 1931, at the Massachusetts Institute of Technology, under the auspices of the Department of English and History.

long afterwards led up to the same idea by a purely mathematical path, but so far as I know, none of them recognized, in the refined mathematical idea of the potential of two circuits, Faraday's bold hypothesis of an electrotonic state. Those, therefore, who have approached their subject by the way pointed out by these eminent investigators who first reduced its laws to a mathematical form have sometimes found it difficult to appreciate the scientific accuracy of the statements of laws which Faraday, in the first two series of his "Researches" has given with such wonderful completeness.

The scientific value of Faraday's conception of an electrotonic state consists in its directing the mind to lay hold of a certain quantity, on the changes of which the actual phenomena depend. In spite of the fact that the experimental researches of Faraday do not contain a single line of mathematics, Maxwell refers to him as one of almost unrivaled mathematical insight. Speaking in another place he remarks:

> It was perhaps for the advantage of science that Faraday, though conscious of the fundamental forms of space, time and force, was not a professed mathematician. He was not tempted to enter into the many interesting researches in pure mathematics which his discoveries would have suggested if they had been exhibited in a mathematical form, and he did not feel called upon either to force his results into a shape acceptable to the mathematical taste of the time, or to express them in a form which mathematicians might attack. He was thus left at leisure to do his proper work, to coordinate his ideas with his facts, and to express them in natural, untechnical language.

A guiding principle which we find operative again and again in Faraday's activities is his belief in the unity of nature, the belief that the various phenomena which manifest themselves in different ways through magnetism or electrically, etc., are all fundamentally of the same kind. Indeed in these researches on the induction current, he speaks of the evolution of electricity from magnetism.

It had been observed by Arago that if a plate of copper be revolved close to a magnet needle suspended in such a way that the latter could rotate in the plane parallel to that of the former, the magnet tended to follow the motion of the plate. Faraday proceeds to discuss this phenomenon and to develop the theory of its action. Then he sets up an experiment in which he revolves a copper disc between the poles of a magnet and makes contact between the edge and the center to a galvanometer. A continuous current is produced, and the first dynamo is in operation. He then applies these ideas to the induction of current in the earth as a result of its rotation in its magnetic field, and draws interesting conclusions concerning the effects upon terrestrial magnetism. He makes experiments upon earth currents on the Thames, and obtains the permission of the king to make experiments at the lake in the garden at Kensington Palace.

At the present time, when our views as to the significance of an electric current have become so concrete, it is well to remind ourselves that in the early stages of the sciences it was by no means obvious that those things which we now call electric currents were of the same character regardless of their mode of production. The realization of a current of electricity from electrostatic charges, from a voltaic cell, and from electromagnetic induction, involves such a diversity of methods in the production of the phenomena that, in the early history of the subject, the question of the identity of electric currents produced by different means was one whose solution was by no means obvious. The importance of a solution to the problem was very evident to Faraday. "It was essential for the further presentation of my inquiries," he writes, "that no doubt should remain of the identity or distinction of the electricity excited by different means." Then by a series of carefully planned experiments he proceeded to test this all-important question and to reach the solution that the apparent differences, striking as they may be as regards the method of production of the current, have no effect whatever upon the nature of the current itself. The high spot in his demonstration of the similarity of different kinds of current was attained in his showing that all of them were able to produce decomposition of certain chemical compounds into their element. These researches led him into a careful examination of the subject which we now know as electrolysis.

That the chemical substances could be broken up by the agency of an electric current was well known, but the mechanism of the process was in a very unsatisfactory state. It was generally assumed that the conductors by which the current entered and left the solution produced an electric field which had the power of tearing the atoms asunder. Faraday realized that such a procedure was entirely inadequate to account for the facts; for, apart from all other considerations, on such a view, it would follow that the slightest electrical tension would be more powerful than the strongest bonds of chemical affinity, since the slightest current would cause chemical decomposition. By an elaborate series of experiments attacking the matter from all sorts of points of view, he finally established the conclusion that the rate of chemical decomposition in any given substance is absolutely independent of all consideration other than the current which passed through it. It matters not whether the electrodes are small or large or even whether there be any electrodes at all. The current alone was the quantity which played the vital part. And so Faraday established his well-known First-Law of Electrolysis; and his celebrated voltameter, whose action rests upon the definite proportionality between rates of chemical decomposition and current, served for many years as the only practicable method by which quantities of electricity could be accurately measured. In connection with these various researches he came to the establishment of certain well-known terms which exist in the literature of the subject to-day. The wires by which the current entered and left the substance which was being decomposed he termed the electrodes, and the substance which was deposited upon those electrodes he called "ions" or "wanderers." The substances which went to these electrodes he called, respectively, anions and kations. One of the electrodes he called the anode and the other the kathode. To the decomposition itself he gave the name electrolysis and substances which were capable of being disintegrated by the electric current he termed electrolytes. It is a characteristic feature of Faraday's mental process that, while he thought of the working entities of nature in a most realistic way, having formulated his concepts, he sought to remove from them as many irrelevant appendages as were unnecessary for the performance of their desired functions. The very term of electricity itself was somewhat distasteful to him as implying a type of mechanism which was not necessarily a unique representative of the experimental facts. Continuing his study of the decomposition by the electric current, he finally came to the formulation of his second law of electrolysis which states that if the same current be passed through different electrolytes in series, the weights of the different substances deposited in a given time are proportional to the chemical equivalent of the substances.

He next takes up the question of the origin of the electromotive force in the voltaic pile, which, it will be recalled, consists of an alternating series of the following kind. First, we have a copper disc, then a piece of blotting paper soaked in a solution, then a zinc disc, then another copper disc, then another piece of paper and so on. It had been customary to suppose that the seat of power in this pile lay in the contact of the metal surfaces, and such a theory was supported by many eminent philosophers. Faraday had become imbued with the conviction that the production of the electric current was associated with chemical decomposition. His experiments on electrolysis showed that the current passing through an electrolyte caused such decomposition, and in the mechanism of the voltaic cell itself he saw a similar phenomenon taking place, the only difference being that here the chemical action took place in the reverse manner.

> The contact theory [he urged] assumes that a force which is able to overcome powerful resistance, as for instance that of the conductors, good or bad, through which the current passes, and that again of the electrolytic action where bodies are decomposed by it, can arise out of nothing: that without any change in the acting matter, or the consumption of any generating force, a current shall be produced which shall go on forever against a constant resistance or only be stopped as in the voltaic trough, by the ruins which its exertion has heaped up in its own course. This would indeed be a creation of power, and is like no other force in nature. We have many processes by which the form of the power may be so changed that an apparent conversion of one into the other takes place. So we can change chemical force into the electric current, or the current into chemical force. The beautiful experiments of Seebeck and Peltier show the convertibility of heat and electricity; and others by Oersted and myself show the convertibility of electricity and magnetism. But in no case, not even in those of the Gymnopodous and Torpedo, is there a pure creation or a production of power without a corresponding exhaustion of something to supply it.

Here in this statement, made before the time when Meyer had published his "Essay on the Forces of Inorganic Nature," and before Joule had performed his experiments upon the mechanic equivalent of heat, we have a foreshadowing by Faraday of the principle of the conservation of energy.

These investigations in electrolysis and the like occupied him until the end of the year 1834, when his attention was directed to the whole question of electrostatic induction. The poles of the voltaic battery had suffered a great loss of prestige in his hands. He seems to see in them nothing but flag poles announcing what is going on in the medium between them, and so he becomes suspicious of the whole idea of electric charges on conductors acting upon each other through the intervening medium. He sees that a so-called charged body can induce a charge on another one which is screened from it in the optical sense, *i.e.*, in the sense that one body would be invisible from the other. The effect attributed to the body A has a mysterious property of being able to travel around the corner and visit body B. And so he comes to concentrate his mind more upon the medium itself than upon the so-called charges on the various bodies. The body is to him merely the means by which the action of the medium is supposed to become apparent. Moreover, the charge distribution produced on the body B by the presence of a charged body A is altered by changing the nature of the medium between the two, as, for example, by the interposition of a sphere of wax. Thus action at a distance has to take some cognizance of the medium between. He sees the medium as a seat of some kind of strain associated with his lines of force. A dielectric is a substance which is capable of sustaining the electrical strains, while a conductor is one which for reasons at the time unknown was unable to withstand it and yielding to it gives rise to an electric current. Hence these lines of electric force end abruptly when they fall upon a conductor. The electric charges (and Faraday dislikes the very word charge) which appear on the conductors are thus only the termination of these lines of force, one end of the line being positive and the other end negative. Like stretched cords these lines tend to contract while they exert also a lateral repulsion against each other which holds them in equilibrium. It was not until a much later date that Maxwell represented in elegant mathematical form this concept of Faraday, and actually found the magnitudes of the pressure and tension which it was necessary to associate with the medium in order that the lines of force as Faraday conceived should hold themselves in equilibrium. When one reads through Faraday's experimental researches and finds in them no mathematical formula, one sometimes wonders whether a person of his intuitive powers of conception may not, as a result, have limited his vision as to the generality of the possibilities. The more closely we read, however, the more we see that even when delving in those realms which are the natural field of mathematical analysis, he has an uncanny way of knowing exactly what he is doing. His concepts developed in terms of lines of force grew stronger and stronger during the whole of his life of investigation; and, yet, he was fully aware of the fact that in spite of the great reality with which the lines stood out to him in his thought, they were only one way of viewing the phenomena, but a way which he regarded as particularly efficient for the purposes of those phenomena. Writing at a much later date he says, speaking of magnetic lines of force, although the arguments are the same:

> Now it appears to me that these lines may be employed with great advantage to represent the nature, condition, direction and comparative amount of the magnetic forces; and that in many cases they have, to the physical reasoner at least, a superiority over that method which represents the forces as concentrated in centres of action, such as the poles of magnets or needles; or some other methods, as, for instance, that which considers north or south magnetisms as fluids diffused over the ends or amongst the particles of a bar. No doubt, any of these methods which does not assume too much, will, with a faithful application, give true results; and so they all ought to give the same results as far as they can respectively be applied. But some may, by their very nature, be applicable to a far greater extent, and give far more varied results, than others. For just as either geometry or analysis may be employed to solve correctly a particular problem, though one has far more power and capability, generally speaking, than the other; or just as either the idea of the reflection of images, or that of the reverberation of sounds may be used to represent certain physical forces and conditions; so may the idea of the attractions and repulsions of centres, or that of the disposition of magnetic fluids, or that of lines of force, be applied in the consideration of magnetic phenomena. It is the occasional and more frequent use of the latter which I wish at present to advocate.

The researches on electricity and magnetism so far reviewed occupied Faraday for a period of about ten years. A few personal incidents of this period are of interest. Sir Robert Peel, with the idea of rewarding and encouraging science and literature, had instituted the system of the Royal Pension to be granted to men of distinction, the grants being made in such a form as to render them acceptable without the appearance of receiving charity. One of these pensions was intended for Faraday, but Sir Robert Peel was out of office before the matter matured in his case, and it fell to the lot of the new prime minister, Lord Melbourne, to invite Faraday to an interview upon the subject. His lordship was evidently not sympathetic with the whole proposal and evidently conveyed his impression during the conversation. It is said that he referred to this giving of pensions to scientific and literary men as so much "humbug," and it is even said that he qualified the word humbug with an epithet which Faraday described as "theological." Faraday's dignity was hurt and he brought the interview to a close. A few hours later, he called upon the prime minister, and left his card with a note, "Declining to accept at your Lordship's hand that which through it has the form of approbation, is of the character which your Lordship so pithily applied to it." Lord Melbourne seems to have treated the matter at first as a joke, but being made conscious of its seriousness by friends who had a greater appreciation of Faraday's work than he had, and being, moreover, apparently a good-natured kind of soul, he became anxious to put the matter through in spite of all. However, Faraday would have nothing to do with the pension until the offensive word had been withdrawn and apologized for. It is a happy reflection upon the character of Lord Melbourne that he saw a greater salvage of the dignity of England's prime minister in honorable retraction of the offensive words than in resting dignity upon the false pride of office, and leaving a shadow which in later years could only have filled with chagrin the hearts of those who respected him.

The strain of the years of activity upon which Faraday had spent his energy up to the end of the first period of his electrical researches had resulted in repeated attacks of bad health, the attacks taking the form of headaches, dizziness and occasional loss of memory. He would be apt to forget some of the experiments that he himself had performed and was unable to make use of his own investigations for the purpose of further advance. At the beginning of 1841 the trouble became so pronounced that he was advised to take a complete rest; and, for a year his work at the Royal Institution was interrupted. His rest took the form of a trip abroad in which as usual he gives a most detailed account of what he did and saw. The beauties of nature are a never-ending source of delight to him, and finally he and his wife returned to England at the end of the year, his health much improved, although it is doubtful if he ever completely recovered from his breakdown.

The second period of his researches occupied the years from 1845 to 1855. Faraday was endowed with an overwhelming conviction concerning the unity of nature, and he was continually trying to see relationships between different parts of science which at first seemed disconnected. The first paper of his second series of experimental researches in electricity dealt with the rotation of the polarization of light in a magnetic field. It has a rather curious title "The Magnetization of Light and the Illumination of Magnetic Lines of Force," a title which gave rise to some misunderstanding as to its significance. The paper starts with the sentence:

> I have long held an opinion, almost amounting to conviction, in common I believe, with many other lovers of natural knowledge, that the various forms under which the forces of matter are made manifest have one common origin; or, in other words, are so directly related and mutually dependent that they are convertible, as it were, one into another, and possess equivalents of power in their action. In modern times the proofs of their convertibility have been accumulated to a very considerable extent, and a commencement made of the determination of their equivalent forces.

In a later paper he proceeds to test a possible relation between gravity and electricity, endeavoring to obtain electric currents by moving coils in the earth's gravitational field in all sorts of different ways. These experiments bear no fruit, but he nevertheless ends the description of them with the statement, "Here end my trials for the present; the results are negative but they do not shake my strong feeling of the existence of a relation between gravity and electricity, though they give no proof that such a relation exists." To this period of Faraday's activities belongs his discovery of the magnetic characteristics of materials. The words "paramagnetic" and "diamagnetic" are introduced by him, and he makes an exhaustive examination of these phenomena in all sorts of different substances including gases. He is particularly interested in the paramagnetic characteristic of oxygen, and thinks that he sees in it, when combined with the temperature variations, an explanation of the variations of terrestrial magnetism. Then we have a long discourse on lines of magnetic force within and without a magnet, and the citation of many of those experiments on unipolar reduction which have occurred so frequently in discussion in the literature, up to the present time. An experiment cited by Faraday is one in which a cylindrical magnet is mounted so that it can revolve about its axis. A wire is joined from one pole of the magnet to the equatorial belt of the magnet through a galvanometer. It is experimentally found that on rotating the magnet and wire together no current is observed in the galvanometer. On the other hand, if either the magnet or the wire be rotated separately a current is produced. The explanation of these effects is one which has puzzled a great many people. In fact, physicists divide themselves into two classes. First we have those who are familiar with the mathematical theory, and to them everything is perfectly clear in the sense that it is all explained by the equations. Then there are those who think intuitively in terms of lines of thought, and in whom a large part of their knowledge of the subject is bound up in the statement that when lines of force cut across a conductor either by the motion of the field or by the motion of the conductor, an electromotive force is produced which is proportional to the rate of cutting off the line. Arguing on this basis, they find a great deal of difficulty in understanding the experiment. They are apt to think of those lines of force of the magnet visualized in the shape of material threads attached to the magnet, so that when the magnet is rotated, these lines partake of the rotation. Such a state of affairs leads to erroneous conclusions as regards the currents excited. The mathematical theory leads to the conclusion that any interpretation which is to be made in terms of the cutting of lines of force must be one in which the lines of force of the magnet do not participate in the rotation. On the other hand, if one takes the magnet as a whole and moves it without rotation in the vicinity of a wire circuit, the electromotive force is accurately calculable in terms of the rate of cutting of the lines, where those lines are considered as carried along with the magnet in its motion. It is an astonishing thing that a large number of physicists who are keen in their judgment but do not happen to have the mathematical technique at hand find the greatest difficulty in getting the right point of view in this matter. Nevertheless, Faraday, who was in this group in the sense that he did not have the mathematical technique wherewith to handle the equations, and in fact the equations did not exist at that date, had formed a perfectly definite conception of the attitude which must be adopted toward lines of force and their motion in order that the conclusion to be expected should agree with the facts. Thus he writes:

When lines of force are spoken of as crossing a conducting circuit they must be considered as effected only by the translation of a magnet. No mere rotation of a bar magnet on its axis produces induction effects on circuits exterior to it; for then, the conditions above described are not fulfilled. The system of power about the magnet must not be considered as necessarily revolving with the magnet, any more than the rays of light which emanate from the sun are supposed to revolve with the sun. The magnet may even in certain cases be considered as revolving amongst its own forces, and producing a full electric effect, sensible at the galvanometer.

This statement shows that Faraday had no difficulty at all in adjusting his mental attitude so that a motion of lines of force along with the magnet when in translatory motion was in every way consistent with a view which considered them as stationary in respect to the rotation of the magnet. If one tries to visualize these lines too completely, there is a danger of an inconsistency arising between these two view-points. How is it possible, one may say, that the magnet can rotate without its line going around with it like a squirrel cage? It is an example of the peculiar power of Faraday's reason that he was able to see just how far he could materialize the association of these lines with the magnet so as to give him the maximum of mental satisfaction without forcing into them a spurious concept of reality in relation to their attachment to this magnet which would have been contradictory to the facts. Another example of his power to make physical intuition his servant rather than his master is found in his supposing that in the case of a bar magnet, for example, the lines of force pass continuously around the outside of the magnet through the magnet itself, so that in the substance of the magnet they travel in the opposite direction to the field one would think of there, if he pictured to himself the magnet simply as a pair of poles. In spite of the fact that this property of magnetic lines of force, or rather lines of induction, as we have come to call them in this case, is insisted upon in all the text-books, I wonder if there are many students in the unsophisticated stage who really understand what is meant. If one tries to think of the phenomena in terms of a magnet made up out of smaller magnets, each with a pair of poles, the magnetic induction within the substance assumes the form of a mathematical vector to which there is no direct physical significance in the sense in which one pictures the actual forces between the various elementary poles of which the little magnet is composed. Even if the elementary magnets be replaced by amperian current whirls or by rotating electrons, the actual field within the interstices of the atoms assumes a highly complex form, and it is only in the sense of an average quantity that this vector, the magnetic induction within the substance, assumes a concrete form. However, it is a quantity which is certainly definite in the same sense that the average magnetic energy of a whole lot of molecules is a perfectly definite thing, a thing in fact directly associated with the temperature of the substance; and, to Faraday, the quantity became concrete as soon as it was possible to define it in terms of its properties. He early seized upon the fundamental characteristics of these lines of force or induction, the characteristic which provides for what in the mathematical theory is called the solenoidal condition, the characteristic which provides for the fact that the total flux of lines through any closed surface is equal to zero, so that the outward flux through one portion of the surface is equal to the total inward flux through all the other portions. In speaking of this matter he speaks with a conviction which goes even beyond the mere experimental requirements that a conclusion must be true. For he says:

I regard the destruction of force, and still more emphatically of one form only of a dual force, is as impossible as the destruction of matter. All that is permitted under the general laws of nature is a displacement of the force and these conditions are as true of the smallest suppressions of force or part of a force as of the suppression of the whole.

His picture of electromagnetic phenomena becomes painted entirely in terms of these tubes of force. It is in terms of the rate of change of flux through a surface that he ultimately expresses the story of the induced current therein; and so through the agency of these tubes of force he realizes what is now to him the physical significance of that quantity which in his early researches he associated with what he called the electrotonic state, the quantity which in the hands of Maxwell figured as the electromagnetic momentum of the circuit concerned. The concept of polarity becomes repugnant to him in electrostatics and in magnetism, as it had become repugnant to him in the theory of the voltaic cell. He raises the question, "What is magnetic polarity and how is it to be defined?" He goes on to say, "For my own part, I should understand the term to mean the opposite and antithetical actions which are manifested at the opposite ends or the opposite sides of a limited, for instance, or unlimited, portion of a line force." Later he says, "If the term polarity has any meaning which has reference to experimental facts and not to hypothesis which is not included in the above description, I am not aware that it has ever been distinctly and clearly expressed."

In all these researches of Faraday, one has to remember that he was working in a time when one did not think in quantitative terms, as we do to-day. There was no ohm, no ampere and the like in terms of which to talk. When he speaks of measurements he talks in such terms as: "the voltaic current which I used upon this occasion was that of five pair of grove cells. The electromagnets were of such power that the poles would seem to sustain a weight of from twenty-eight to fifty-six or more pounds." Then again when citing experiments on the effects of different quantities of charge he talks of the number of rotations which he makes in the wheel of his electrical machine. On the other hand, in these experimental situations, just as in his theoretical discussion, he shows an intuition so well described by one who said, "He smells the truth." In using the crude galvanometers of the day to investigate some of the phenomena of induction, he comes to the conclusion that it is better for the purpose in hand to use an instrument with one turn in its coil than to use one with many. For he says, "Such a wire had abundant conducting power; and though it passed but once around each needle, gave a reflection many times greater than that belonging to the former galvanometer." Again when he is obtaining current from a battery of cells he finds that it is better to join them up in a combination of what we call series and parallel, than to adopt either of these methods exclusively. The only place where he gives a suspicion of failing in a minor way to recognize the full significance of the elements involved is where, on making a simple arithmetical calculation concerned with measurements which are necessarily rough and semi-qualitative in nature, he expresses his calculations and results to seven significant figures.

Some of his last work concerns meditations on the nature of light which he tried to visualize simply as undulations of his line of force; and, while he did not carry the development of this matter very far, it is significant that here also he "smells the truth"; for, as so vividly portrayed in the calculations of radiations, we see the essential element of the electromagnetic waves, from a charged particle in motion, for example, as resulting from a super-position of ripples upon the lines of force of the charge in such a manner as to leave intact the permanence of those lines of force as regards the constancy of their flux through a closed surface surrounding the charge.

And so we come to the close of the career of this great prince of experimentalists whose labors fired the spark which has illuminated the whole realm of modern physics. As age crept on, his forgetfulness increased more and more. His last lecture was delivered in 1862, and the same year saw his last experiment. As he felt his powers weaken he laid aside his duties one by one. He was invited to assume the presidency of the Royal Society but declined. It was inevitable that the managers of the Royal Institution should feel it fitting that, as his career drew to a close, he should be asked to be president of the institution to which he had brought such lasting fame. But he felt that the duties of this position, if conscientiously performed, would be beyond his powers at the time, and he was not one to take the task and, in carrying it through, fall below the standard set by his very high ideals. The closing years of his life were spent near Hampton Court in a house placed at his disposal by the Queen in 1858; and it is a comforting thought that in spite of the weakening of his powers time treated him kindly as regards his general health. He suffered from no disease, and his end came without pain on the 25th of August, 1862, while seated in a chair at his desk.

OBITUARY

NORIFUMI OKAMOTO

ON February 17, 1931, Japan lost one of the foremost scholars in the field of the history of her native mathematics, Mr. Norifumi Okamoto. In the oriental countries it is not enough that such a man should be well versed in mathematics as a science; for this he may be without the ability to read with any ease the works of the classical writers of his own language. This is due to the fact that modern mathematics makes use of terms and methods unknown to ancient writers, whereas the terminology used by the latter is like medieval Latin words to a modern student of analysis. In the person of Mr. Okamoto both necessary elements for the interpretation of the classics were combined, for in his youth, before the Restoration, he was taught the mathematics of the past, and after the abolition of the shogunate he took up the study of the occidental works in the same field. He was one of a band of young and enthusiastic teachers to make the first Japanese translations or adaptations of European text-books and thus to bring into the modern schools of his country the ideas of the western world.

When the Japanese government decided to establish normal schools as part of its modernizing program he was appointed the principal of one of these institutions, and when the Peers' College was founded it was to him that the authorities turned for advice,