ADDRESS TO THE WESTERN CENTRE*

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FOUR GREAT BRITISH ELECTRIC LIGHTS: FARADAY—THE DISCOVERER; MAXWELL—THE INTERPRETER; KELVIN—THE MEASURER; SILVANUS THOMPSON—THE TEACHER.

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In a science like our own which has sprung from almost entire ignorance within a space of less than 100 years, it is not amiss, when a certain phase has terminated, to try to review in some perspective the great figures which have taken part in that phase and to compare the parts which each of them has taken in it. In selecting the above four figures, I do not wish for one moment to suggest that they alone have contributed to bringing our science to the state of development it had reached some 10 or 15 years back; nevertheless, they do represent certain distinct parts of the whole, and the individuals' names were, in themselves, those of such outstanding characters that it is a fair generalization to state that they almost entirely made possible the advancement of electrical science which took place between, say, 1830 and 1910.

MICHAEL FARADAY—THE DISCOVERER.

Michael Faraday was born in 1791 at Newington in Surrey, his father being a Yorkshire blacksmith who had moved from Ingleton, near Settle in Yorkshire, to the South of England. Michael Faraday appears to have had very little education in the ordinary sense, but he was eventually apprenticed in London to a bookbinder of the name of Riebau, and, when binding books that were brought to his master, he availed himself of the opportunity to dip into some of them, and in this way he was evidently able to absorb his first knowledge of scientific subjects. His mind thus inspired with the idea, he attended lectures on natural philosophy, and on one occasion one of his master's customers, named Dance, took Faraday to hear four lectures delivered by Sir Humphry Davy at the Royal Institution. He made copious notes of these lectures, which he transcribed, and then bound up and sent to Sir Humphry Davy, asking him to interest himself in obtaining for him some employment in scientific work. At the time nothing came of it, but a year later, Sir Humphry Davy's laboratory assistant leaving the Royal Institution, the post was offered to Faraday and accepted, at the magnificent salary of 25s. per week and two rooms in the Royal Institution.

The following year he accompanied Sir Humphry Davy, in the capacity of secretary, on a tour through France, Italy and Switzerland, meeting on this journey, which lasted nearly two years, nearly all the principal scientific men then in Europe. On his return he again took up his work at the laboratory, of which in 1825, on Sir Humphry Davy's retirement, he was appointed Director.

In 1833 Faraday was appointed Fullerian Professor of Chemistry at the Royal Institution, a life appointment without obligation to deliver lectures.

This is not the place in which to recount the whole of Faraday's work, because I wish to lay stress on his part as an electrical discoverer. His scientific researches on electrical work fall broadly into three periods. The first of these, lasting from 1816 to 1830, was mostly occupied with chemical work. The second, lasting from 1831 to 1839, covers the period of the experimental researches in electricity and magnetism which are indeed the foundation of our science. The third period, from 1860 to 1862, also covers further electrical researches, immensely important in themselves, but not of the importance that this second period covered. Between 1839 and 1844 Faraday had been obliged to suspend serious work owing to a breakdown of his health, and the last series of his investigations came to an end for the same reason.

Let us imagine ourselves at the starting-point of Faraday's electrical work. In 1820 Oersted had discovered, it is generally believed, by an accident in the course of one of his lectures, that a compass needle was acted upon by an electric current in a wire. But there is no doubt that Oersted had been looking for some connection between the electric current and magnetism, although up to this date he had not found any.

The announcement of this discovery, in Faraday's own words, "burst open the gates of a domain in science, dark till then, and filled it with a flood of light."

Ampère, Laplace and Davy added very rapidly to a full knowledge of the reaction between magnets and electric circuits, and between electric circuits themselves.

Dr. Wollaston, having suggested that there ought to be a tendency when a magnetic pole was presented to a conducting wire for that conducting wire to revolve around its own axis, went to the Royal Institution in April 1821 to make an experiment. He did not realize

* For the historical facts given in this Address the author has made free use of, and desires to acknowledge his indebtedness to, the following works:—
S. P. THOMPSON: "Michael Faraday, his Life and Work"; and "The Life of William Thompson, Baron Kelvin of Largs."
R. ROUTLEDGE: "A Popular History of Science."
L. CAMPBELL and W. GARNETT: "The Life of James Clerk Maxwell."
J. S. THOMPSON and H. G. THOMPSON: "Silvanus Thompson, his Life and Letters."
Encyclopædia Britannica, Miscellaneous Articles.

the result he expected, but Faraday's attention having been thus called to this point, he went to work and discovered that a wire included in an electric circuit hanging vertically over a magnetic pole with the lower end dipping into a pool of quicksilver would rotate around the pole of the magnet, or, conversely, if the wire were fixed and the magnetic pole free to move, the latter would rotate around the former. The various modifications of this experiment were subsequently contrived. In this device we have the first electric motor, being what we should now call of the homopolar type.

This was the only electrical discovery of importance in what has been termed the first period of research, but doubtless his mind had been occupied from the year 1823 onwards in pondering on electrical matters, and in the meantime Sturgeon had invented the soft-iron electromagnet in which an iron core surrounded by a copper wire is magnetized when a current passes. Faraday was firmly convinced that a reciprocal action, that is to say, the conversion of magnetism into electricity, could be effected, and even in 1822, following his habit of putting down in his notebook thoughts which crossed his mind and which he proposed later to experiment on, he had written these words: "Convert magnetism into electricity."

We have to bear in mind that at this date the general doctrine of the conservation of energy had not been formulated in any rigid manner, much less proved, and, consequently, these ideas arose from certain intuitions in Faraday's mind that such a result, whilst to be expected, was not a necessary consequence, though to-day, given the one result, the other follows as a mathematical certainty.

Many were the experiments which Faraday recounted of his efforts to produce electric currents from magnets or from coils forming electromagnets, and from 1824 to 1828 he was still relentlessly attacking this problem. In 1831, for the fifth time, he made a frontal attack on the problem, this time with a ring magnet wound with two sets of coils, the one set connected to a battery, the other to a galvanometer, and with this apparatus success was at last achieved, but not in the way he expected. What he and others had been looking for was a steady current produced by the action of magnetism on a coil, just as magnetism is produced and maintained in soft iron by a steady electric current. What he found was, as we now know, the current set up in the second coil when the current in the first coil was started or stopped. Once having achieved this result, he was able to produce the same effect by magnetizing the soft iron core inside the coil by permanent magnets, and a few days later, a copper disc forming part of an electric circuit, the axis and periphery of the disc connected with the galvanometer being placed between the poles of the great horseshoe magnet of the Royal Society, on being revolved gave a steady current which deflected the galvanometer, and thus the magneto-electric generator or, ultimately, the dynamo-electric generator, was born. This last frontal attack with all its splendid results lasted only 10 days. The story of it is given in his "Experimental Researches" and forms a monument to his immense perseverance and, moreover, to his extraordinary intellectual insight.

Following these results and arising out of them, we come to Faraday's discovery of the mutual induction between electric currents in one circuit and those in another circuit, and that the starting, stopping and variation of a current in one wire give rise to transient currents in a neighbouring wire. It was at this time that he first used that idea which in his hands and others was to prove so fruitful, i.e. the idea of the conductor cutting the magnetic curves. He explains: "By magnetic curves I mean lines of magnetic forces which would be depicted by iron filings." These lines of force have been a powerful aid to our understanding of electric and magnetic phenomena.

They may be shown mapped out by iron filings on magnets, and a wire carrying an electric current attracts iron filings on the card threaded on the wire—facts discovered by Davy. The circles show the lines of magnetic force, whilst a circular conductor in section illustrates how these lines form circles around each conductor and through the centre of a ring or coil.

All the results which Faraday discovered as to the induction of circuits and of magnets, whether by their mutual motions or by changes in the currents, he was eventually able to summarize in that idea which has never been replaced by any better generalization: the idea that an electromotive force is set up in a circuit and a current produced if the circuit is closed, whenever the circuit cuts the lines of force of a magnet existing in the neighbourhood of a circuit carrying a current.

In the series of discoveries which I have outlined, starting from the original discoveries of Oersted and Ampère, Faraday had completed our knowledge of electro-dynamics.

In 1833 Faraday published another series of researches on electro-conduction, giving an extraordinary collection of observations on the conducting power of liquids, solids, fused salts and other bodies, interesting even at this date in themselves, but important in particular as leading to the study of what we now know as electrolytic conduction, and here again Faraday achieved results of the most far-reaching consequences. He discovered that the amount of decomposition of electrolytic bodies with definite electric quantities was proportional to the electro-chemical equivalents of the substances being acted upon, or direct multiples of these equivalents, and he was led to the following statement:

"According to it [this theory] the equivalent weights of bodies are simply those quantities of them which contain equal quantities of electricity or have naturally equal electric powers, it being the electricity which determines the equivalent number because it determines the combining forces. Or if we adopt the atomic theory, or phraseology, then the atoms of body which are equivalents to each other in their ordinary chemical action have equal quantities of electricity naturally associated with them."

There, in fact, is stated the doctrine of the atomic charge, or that "electron" which all the investigations since that date have established as the unit of electric action, and which, we may certainly say to-day, is the foundation of the atom.

In 1835 Faraday considered the question of whether electricity resides upon the surface of the conductor or upon the surface of the dielectric in contact with it, and he arrived at this conclusion:—

"Electricity appears to exist only in polarity as in air, glass, electrolytes, etc. Now metals being conductors cannot take up that polar state of their own power, or rather retain it, and hence probably cannot retain developed electric forces."

Here again, Faraday had reached, in the course of a few weeks' experimental work, the great truth to be developed by those who followed him, i.e. that all the phenomena of electrostatics lie in conditions set up in non-conducting or dielectric materials and not as some emanation from the boundaries of the conductor.

Omitting many important researches, I will now come to the third period of Faraday's activity when, after a period of rest, during which fresh ideas were doubtless being organized in his mind, he attacked the problem of whether there was any action or connection between electricity or magnetism and light. Ordinary light consists of undulations in the ether in all planes along the direction of the light ray, but, previous to Faraday's time, the phenomenon of polarized light, or light vibrating in one plane only, had been discovered, and moreover it had been found that such light when passed through substances having a crystalline structure, or in which by applied stresses strains are set up, has the property of rotating the plane of the vibration. It was with polarized light that Faraday commenced his experiments. He worked first with liquid electrolytes through which the electric current was made to pass, but without result. He tried numerous solid dielectrics under electric stress to see if they would give him any result. In every possible way were electric stresses set up in these materials, and pages of his notebook are filled with negative results. Then he substituted magnetic for electric forces and again worked upon air, flint, glass, rock crystal, calcareous spar, etc., but with no result. At last he tried a piece of "heavy glass" (boro-silicate of lead), a glass which he himself, after four years of work in his early scientific career, had developed for optical purposes, and at last, using a powerful electromagnet so arranged that the lines of force passed along this glass in the same direction as the polarized light, a movement of the plane of polarization was observed. Experiments here show that the result was only obtained in so far as the light ray passed along in the same direction as the lines of magnetic force. Having achieved this result, he obtained a more powerful electromagnet and was then able to produce the effect, even with some of the substances with which he had hitherto failed. Thus he established that there is a definite connection between magnetic phenomena and light, a connection which we shall see later became so fruitful in the hands of Maxwell, but more than that, arising out of these experiments and out of the use of the bar of heavy glass already mentioned, and of the powerful magnet which he had borrowed for the purpose of the foregoing experiment, he made a further great discovery, that of diamagnetism, a property of many materials by which, instead of being attracted like iron filings, they are repelled from a single pole of a magnet or, if in the form of a bar or needle, set themselves across the lines of magnetic force instead of along the lines of magnetic force as in the case of iron.

Among all these experimental discoveries we find in Faraday's work his inability to accept the ideas, then current, of action at a distance, that is to say, the idea that forces could exist between the material substance without any intervening substance through which the action was to be transmitted, and in this relation he constantly expressed his results in terms of lines of magnetic force, viewing them as something physically existent but acting he knew not how, and of which he used the following phrase:

"Such an action may be a function of the ether, for it is not at all unlikely that if there be an ether it should have other uses than simply the conveyance of radiation."

The outstanding feature of all Faraday's work lies in the power which he possessed of visualizing, in some way that seemed peculiar to himself, possible actions and interactions which he put to the test of experiment. That these visualizations produced in his mind great certainty as to the results, is clear from the way in which he persistently followed a given line of thought, returning again and again by new experiments until he had arrived at the result which he foresaw.

Faraday, as will be shown later, was not only no mathematician in the ordinary sense, but was practically ignorant of mathematical methods. The forecasting of new results of mathematical processes and their subsequent examination experimentally is a procedure to which scientific men have long become accustomed, but Faraday substituted for that mathematical process some mental process of his own with a power of insight which has probably never been equalled by any other true experimenter, before or since.

Let us summarize some of his discoveries in electrical science:

(1) The possibility of an electric motor, or continuous movement arising from electric current and magnetic fields.

(2) The induction of currents between conductors across an intervening space.

(3) The production of electromotive forces and electric currents by the mutual movement of electric conductors and magnetic fields.

The electric motor, the transformer and the induction coil, and the dynamo, lie in these discoveries.

(4) The electric valency of substances in electrolysis, and the realization of the electric unit in which much of our present electrolytic knowledge and our insight into the structure of the atom and the first suggestion of the electron were contained.

(5) The action of the magnetic field in rotating the plane of polarized light, in which were the germs of the electromagnetic theory of radiation and all that is therein involved.

(6) Diamagnetism, i.e. the repulsion of bodies under magnetic force, which leads to the strong presumption

of the truth of Ampère's hypothesis of the cause of magnetism as lying in the molecular electric currents circulating in the compound atoms or, as we now view it, in the rotation of the electron in the atom of which it forms a part.

Truly, indeed, are we entitled to regard Faraday as the Discoverer.

Maxwell—The Interpreter.

James Clerk Maxwell was born on 31st January, 1831, at the period when Faraday was commencing his second series of researches, his father being John Clerk Maxwell of Penncuick, Midlothian, a lawyer owning the estate of Middlebie, and it was on this estate to a large extent that Maxwell was trained. In very early youth he showed signs of great ability and, his mother having died when he was nine years old, he was encouraged in early nature studies by his father, who himself appears to have had a good understanding of scientific subjects.

When Maxwell was 15 years of age he had already commenced original studies on geometrical problems, and the results were communicated to the Royal Society of Edinburgh and appeared in the Proceedings of that Society as a communication from Professor Forbes of a paper by Mr. Clerk Maxwell, Junior.

In 1847 at 16 years of age he entered the University of Edinburgh, having already done much original work in mathematics and mathematical physics, and by 1849, when he was 18 years of age, he had already carried out original experimental work on polarized light, properties of crystals, etc.

At the age of 19 he entered Trinity College, Cambridge, and in 1854 disappointed his tutors by becoming second wrangler, Routh gaining the honour they had hoped for him, of being the senior wrangler. The two were declared equal in the examination for the Smith mathematical prize.

In 1855 he wrote "I am reading electricity," and again, "I am getting on with my electrical calculations every now and then and working out anything that seems to help the understanding thereof."

In 1857 we find him in correspondence with Faraday.

From 1860 to 1865 Maxwell was at King's College, London, as Professor of Physics, a great deal of his work there being optical, but nevertheless notable for the experimental measurements in which he took part with Balfour Stewart and Fleeming Jenkin in the determination of the British Association standard ohm.

From 1866 to 1870 he carried out experimental work in his country home in Scotland, and it was during this time that much of his "Treatise on Electricity and Magnetism" was written. It was not until 1871 that he was appointed the first Cavendish Professor in the University of Cambridge, his first task being the creation of the experimental Cavendish Laboratory where he and others have made such notable discoveries.

By 1860 Maxwell had already commenced planning in his mind the great work of electricity and magnetism which was to revolutionize electrical theory.

In 1861 he wrote to one of his correspondents:

"I am trying to form an exact mathematical expression for all that is known about electromagnetism, without the aid of hypothesis, and also if the variations of Ampère's formulæ are possible without contradicting his expressions." In the first of these tasks he was successful, but as to the second he arrived at the result that Ampère's formulæ could not be varied without contradicting the experimental results.

His ideas on this subject may well be quoted from the preface to the first edition of his "Treatise." He says "the general complexion of the 'Treatise' differs considerably from that of several excellent works published, most of them in Germany, and it may appear that scant justice is done to the speculations of several eminent electricians and mathematicians. One reason of this is that before I began the study of electricity I resolved to read no mathematics on the subject until I had first read through Faraday's experimental researches on electricity. I was aware that there was supposed to be a difference between Faraday's way of conceiving phenomena and that of the mathematicians, so that neither he nor they were satisfied with each other's language. I had also the conviction that this discrepancy did not arise from either party being wrong. I was first convinced of this by Sir William Thomson, to whose advice and assistance, as well as to his public papers, I owe most of what I have learned on the subject. As I proceeded with the study of Faraday I perceived that his method of conceiving the phenomena was also a mathematical one, though not exhibited in the conventional form of mathematical symbols. I also found that these methods were capable of being expressed in the ordinary mathematical forms and thus compared with those of the professed mathematician. For instance, Faraday in his mind's eye saw lines of force traversing all space, where the mathematician saw centres of force attracting at a distance. Faraday saw a medium, where they saw nothing but distance. Faraday sought the seat of the phenomena in real actions going on in the medium; they were satisfied that they had found it in a power of action at a distance impressed on the electric fluids. When I had translated what I considered to be Faraday's ideas into a mathematical form, I found that in general the results of the two methods coincided, so that the same phenomena were accounted for and the same laws of action deduced by both methods, but that Faraday's methods resemble those in which we begin with the whole and arrive at the parts by analysis, while the ordinary mathematical methods were founded on the principle of beginning with the parts and building up the whole by synthesis. I also found that several of the most fertile methods of research discovered by mathematicians could be expressed much better in terms of ideas derived from Faraday than in their original form." He continues: "I have confined myself almost entirely to the mathematical treatment of the subject, but I would recommend the student after he has learned, experimentally if possible, what are the phenomena to be observed, to read carefully Faraday's experimental researches in electricity. He will there find a strictly contemporary historical account of some of the greatest electrical discoveries and investigations carried on in an order and succession which could hardly have been improved if the results had been known from the first, and expressed in the language of a man who devoted much of his attention to the methods of accurately describing scientific operations and their results."

Such then was the task which Maxwell set himself.

The translation of Faraday's experimental researches into a mathematical form led to the discovery that, having done so, the resulting statement of electrical phenomena is substantially identical with the statement of a mechanical and dynamical science. Maxwell utilized the fact to reduce the science to one of measurement and prediction, and the calculation thereby of the conditions arising in electrical and magnetic phenomena in regions where no experimental work had hitherto been done. This again led to the discovery of the definite relations between electric and magnetic forces and, finally, the representation in concrete form of a mechanism of the ether and a mechanism of dielectrics which complied with all that Faraday and others had shown experimentally in respect of the lines of force and stress of the dielectric medium. This led finally and as a culminating triumph to the electromagnetic theory of light, forming the basis on which the whole question of electromagnetic radiation and, in a practical way, wireless telegraphy has been built up.

It is interesting in relation to Maxwell's exposition of Faraday's work to read what Faraday himself wrote to Maxwell in 1857.

"There is one thing I would be glad to ask you. When a mathematician engaged in investigating physical actions and results has arrived at his conclusions, may they not be expressed in common language as fully, clearly and definitely as in mathematical formulæ? If so, would it not be a great boon to such as I to express them so? Translating them out of their hieroglyphics that we also might work upon them by experiment. I think it must be so, because I have always found that you could convey to me a perfectly clear idea of your conclusions which, though they may give me no full understanding of the steps of your process, give me the results, neither above nor below the truth and so clear in character that I can think and work from them. If this be possible, would it not be a good thing if mathematicians working on these subjects were to give us the results in this popular, useful working state as well as in that which is their own and proper to them?"

Faraday asked a question which has been asked many times. I think the answer may be found in Maxwell's own work. It is true that most of the investigations in his "Treatise" are mathematical, but nevertheless he sets out as the work proceeds both the experimental data on which he proposes to operate mathematically and the results obtained, and in this sense indeed not only was Maxwell a mathematical operator on the experimental results of Faraday, but he clearly expounded the further results which inevitably followed those discoveries.

Faraday's work on the relation of electromagnetic phenomena and light was doubtless the starting-point of Maxwell's investigations therein, and it was by working from these experimental results that Maxwell was led to the conclusion that light and other radiations such as heat are, in fact, electromagnetic disturbances in the ether, and that the velocity of the propagation of an electromagnetic disturbance should be the same as that of light. He showed that the velocity of transmission of electromagnetic disturbances varies inversely as the square root of the specific inductive capacity, and also inversely as the square root of the magnetic permeability of the dielectric. The proof then of the truth of his theory would lie in comparing the refractive indices of substances for light, which depend on the velocity of transmission of light, with the specific inductive capacities of the same substances, and many experimenters set to work on this question. In the result it was established, with some notable exceptions, that for light of infinite wave-length the specific inductive capacity of a dielectric is equal to the square of its refractive index, and there seems no reason any longer to doubt the truth of Maxwell's proposition. Definite mechanical actions in dielectrics and in the all-pervading medium which would explain all the observed facts of electrical and magnetic phenomena were put forward by Maxwell, with the result that it was no longer necessary to entertain the theory of action at a distance, and the point of view of Faraday was definitely established.

The views of Maxwell and his treatment of electromagnetic theory found for some years but little acceptance by the scientists of other nations. The English school of electrical theory indeed was a thing apart, and it was not until the experimental work of Hertz from 1885 to 1887, when there was placed absolutely beyond any further question the identity in the method of propagation of electromagnetic and light waves, that Maxwell's theories and the English school had triumphed.

Thus had Maxwell interpreted Faraday, had completed and crowned as Interpreter the great work of Faraday as Discoverer.

Kelvin—The Measurer.

William Thomson (afterwards Lord Kelvin) was born in June, 1824. His father James Thomson was of Scotch descent, but his family for 200 years had occupied a small farm at Ballyn-a-huish, and his father was brought up on the land as a farm labourer, receiving from his parents the rudiments of his education. But with the Scotch instinct for education he studied himself, and among other things the art of "dialling," or making sundials. It is related of him that when he was 11 or 12 years old he discovered how to make dials suitable for any latitude. He subsequently studied under the Presbyterian minister near his home, and later became a school teacher at his native place, spending six months of the year at Glasgow University. In 1814 he became lecturer on mathematics at the Royal Belfast Academy, and in 1815 was made Professor of Mathematics in the college.

Such was the father of William Thomson, who was the fourth child. If there be anything in heredity, surely it was likely that the son of such a father would exhibit exceptional gifts. When he was 8 years old his father became Professor of Mathematics in Glasgow University, his mother having died two years earlier. Just as in the case of Maxwell, who lost his mother at an early age, the effect of this was a closer contact between father and son than might otherwise have been the case, and undoubtedly this fact had a great bearing on his early training.

In 1834, at 10 years of age, he matriculated in Glasgow University. It is almost unbelievable that a child could undertake the tasks which he performed. As a holiday task for which he received a prize he translated from the Greek Lucien's "Dialogues of the Gods," with full parsing of the first three dialogues. At 16 he received a prize in astronomy and a university medal for an essay entitled "On the Figure of the Earth." As time does not permit me to expand the theme of the intellectual brilliance of this youth, let us see how his attention was turned to electricity and magnetism. There was with him at the university one David Thomson, a cousin of Faraday, and it was by him, Thomson himself stated, that he was inoculated with Faraday's fire. He preached to William Thomson, Faraday's doctrine of action through a medium along lines of force as against the older mathematical doctrine of action at a distance, and finally William Thomson was converted. In 1841 Thomson, now in his 17th year, entered Peterhouse, Cambridge. At 18 years of age he had written and published original mathematical investigations on the flow of heat and distribution of electricity. The results, although it was eventually found that they had been anticipated, had been arrived at by different methods by three of the foremost mathematicians in Europe. But when the examinations arrived he, like Maxwell, failed to become first wrangler, being second and, again like Maxwell, he obtained the Smith mathematical prize.

In 1846 Thomson was appointed Professor of Natural Philosophy in Glasgow University, a post he held until his death in 1907, a period of 61 years. To catalogue the mathematical and physical investigations of this mental giant, the greatest since Newton, would take more than a lecture; problems and discoveries in heat, light, electricity, magnetism, Atlantic cables, cooling of the earth, etc.; there is no end to them; Silvanus Thompson in his biography of Kelvin gives a bibliography of 661 original papers and communications. It is stupendous. From the time he was 10 or 12 until he left us at 73 that colossal brain never stopped working. In 1866 on the completion of the Atlantic cable he received the honour of knighthood, and in 1892 was created Lord Kelvin.

But it is of Kelvin as measurer that I wish to speak. In the session of 1882–3 I attended a course of lectures at the Institution of Electrical Engineers on "The Practical Applications of Electricity," and the last of the course was by Sir William Thomson on "Electrical Units of Measurement." He commenced: "In physical science a first essential step in the direction of learning any subject is to find principles of numerical reckoning, and methods for practicably measuring some quality connected with it. I often say that when you can measure what you are speaking about and express it in numbers you know something about it; when you cannot express it in numbers your knowledge is of a meagre and unsatisfactory kind. It may be the beginnings of knowledge, but you have scarcely in your thoughts advanced to the stage of science whatever the matter may be." Then he recited the case of the hardness of materials expressible only in an empirical scale beginning with the diamond and ending—I forget with what. Then he went on to say that 10 years previously (in 1872) electrical measurement was little better. That in 1858 a practical beginning of definite electrical measurement had been made—standard resistances and condensers in absolute measure had been used on his own initiative in telegraphic and cable work, but these had hardly reached even the laboratories in 1872. He recited how, as early as 1871, he had commenced using the absolute system in the reckoning of electromotive forces of voltaic cells, and the electric resistances of conductors in electromagnetic absolute units, and in 1861 he obtained the appointment of a Committee of the British Association on electrical standards.

Earlier on I have spoken of Maxwell's work at King's College on the experimental determination of the ohm; all this work was initiated by Kelvin and carried out on lines designed by him, and after 10 years' work the absolute system known as the "C.G.S." was launched for general use.

Kelvin did not invent the absolute system; the idea had been put forward by Gauss, a German mathematician and physicist. I should like here to say a few words on the subject of absolute measurement, because a clear understanding is essential to engineers, but engineers are to-day in the position of having such a complete equipment of direct-reading instruments put into their hands that they have ceased to inquire or know how they have been arrived at. But the last generation of electrical engineers, to which Kelvin belonged, had none of these things and were very much occupied in trying to get them. The measurements and calculations of mechanics and dynamics, that is, of matter at rest and matter in motion, can all be compassed by three fundamental units, a unit of length, a unit of mass or quantity of matter, and a unit of time. There is no relation between them and they are all purely arbitrary, and the advantage or disadvantage of any particular units for these quantities lies only in the extent to which they are universally used, with some other advantages or disadvantages arising from the method of connecting them with one another in the compound units. The discussions on the comparative advantages of the British and metric units lie in these latter considerations; both start with purely arbitrary units. The British units are:—of length the distance between two marks on a platinum bar at a certain temperature—we call it the yard; the quantity of matter is the matter in a piece of platinum; the weight or force with which it is attracted to the earth is called a pound; and the unit of time is the 1/86 400th part of the mean time of the rotation of the earth (mean solar day)—we call it a second.

The metric system has a different bar and marks and the distance is called a metre, a different piece of platinum the weight of which in Paris is called the weight of a kilogram, and the same unit of time. But before Kelvin's time, although the dynamical units were understood, scientific and engineering measurements were made in arbitrary units. Thus, forces were measured by the attractions in London and Paris respectively for the aforesaid pieces of platinum, work done by the number of times such a piece of platinum would be raised one unit of length against gravity in a second, and so on. Electrical units were more arbitrary. Electromotive force was specified as being equal to so many Daniell or other cells. Resistances were specified in lengths of copper wire of unspecified properties of a specified size, and current in degrees of deflection of the owner's own galvanometer. It was from this state of chaos that first Gauss and then Kelvin extricated us. Starting with units of length, mass, and time, the unit force was defined as that which, acting on unit mass for unit time gave it unit velocity, that is, an absolute measure independent of place. With these preliminaries Kelvin showed how to build up a complete system of units and measures for all electrical quantities though one or two natural physical quantities intervene. It is true that the apparent number of fundamental units in electrical work is three, as in mechanical work, but there are really four, three arbitrary and one implied. Kelvin himself reminded us that Gauss had already pointed out that only two fundamental units are necessary for mechanical measurement if we imply one. Thus, if we define the unit of force as the force with which at unit distance a particular mass attracts another equal mass, we are bringing in a special property of matter, i.e. its attractive property. If we define the unit of force as that necessary to give a certain unit mass a unit velocity in a unit time, we bring in another property inherent in matter, its inertia, so in each case we really involve something besides the apparently arbitrary quantities of the units. So in electrical units, the existence of electrical states at rest (statical) is known only by the mechanical forces which exist. The existence of electricity in motion (electric current) is shown either by forces exerted or by heating and chemical effects. If we decide to measure by heating and chemical effects we must choose some material substance, the action not being the same on all. Consequently, even in the case of electric currents we have chosen to select mechanical effects which can if necessary be measured *in vacuo*, by which means special substances can be eliminated.

But we must decide whether we are to start by measuring forces arising from electrostatic attractions, or the forces arising from electrodynamic attractions. By choosing the former we arrive at a series of units we call electrostatic units; by choosing the latter we obtain a series we call electromagnetic units.

In the first our primary unit is the quantity of electricity which at unit distance in air attracts an equal quantity of electricity with unit force. Concentrating this quantity on a sphere of unit radius at a distance from surrounding bodies in air, we raise it to unit potential above the surrounding bodies. From these we derive all the other units.

In the electromagnetic system we start with unit force between two magnetic poles at unit distance, and unit current is that which flowing in a unit length at unit distance exerts unit force on a unit pole. The unit electromotive force is that which produces such a current in a unit resistance, and so on. It was the measurement of this resistance which occupied so much of the attention of the Electrical Standards Committee.

It is not difficult to understand the principle. If we have a coil rotated in a magnetic field an electromotive force results; if the coil is a closed circuit a current is produced alternating in direction in the coil, but giving a rising and falling current always in the same direction in space.

If in the centre of the coil we hang a small magnet it is deflected by the current. It is held to its place by the earth's field, but the electromotive force and current also depend on the earth's field, so that we are able finally to express the resistance of the coil as a quantity dependent on the velocity of rotation of the coil. Various corrections for the field of the small magnet, and so on, have to be made. Thus is the unit of resistance determined. The rest follows.

These two sets of units, the electrostatic and the electromagnetic, being based on two different properties of space and matter, the first on the potential energy existing in the dielectric space between charged bodies, and the second on the kinetic energy of a magnetic field, are not related to one another by a constant multiplier, but it was shown by Maxwell that they are related to one another by some power, positive or negative, of a number which is the ratio of the square root of the elasticity to the square root of the density of a medium. But this ratio is the velocity with which a transverse vibration is transmitted in the medium, that is, it is the velocity of light—a deduction which has since been experimentally proved.

Kelvin not only started this work, but he it was who inaugurated the British Association Committee; he it was also who finally suggested the three primary units, the centimetre, the gramme, and the second, and it was largely his influence which obtained international sanction for this absolute system. The electromagnetic system was adopted for general use, but the units were of inconvenient size. The unit of current was about right, but the units of electromotive force and resistance were far too small. So other units were adopted as follows: A unit of electromotive force equal to 10^8 C.G.S. units; a unit of resistance equal to 10^9 C.G.S. units; and a unit of current equal to 10^{-1} C.G.S. units. The series was completed and forms a complete and consistent whole in which the unit of length is 10 million metres, the unit of mass one hundred-thousand millionth of a gramme, and the unit of time one second.

Kelvin himself was the author of a series of very beautiful instruments for making measurements. The absolute electrometer is one, in which the actual attraction is weighed. The quadrant electrometer is another, in which a needle is drawn between quadrants connected to the potential terminals to be measured, and deriving great sensitiveness from the fact that the needle can be charged from an independent source to a known and high difference of potential from the earth. The mirror galvanometer, the ampere balance for the direct weighing of current attractions, and many others all attest to his intense practical interest in carrying out the measurements he had devised. It is the simplicity and extreme accuracy of measurement which has differentiated electric science from almost every other. The way was pointed by Kelvin.

In the 1883 lecture with which I commenced, Kelvin pointed out that there are, in addition to those natural constants, gravitational attractions, dielectric elasticity and electromagnetic force, to which I have alluded, other natural constants which might well be used for determining absolute physical units, and it may be that such will eventually be the units. For example, the second is by no means an ideal unit; it is becoming longer as the time of rotation of the earth increases under the influence of tidal friction; it is conceivable that an air raid might destroy the physical metre and kilogram on which we rely. But the mass of an atom of hydrogen, the length of a wave of light, say of one of the sodium lines, the velocity of light *in vacuo* giving us the time of oscillation of a sodium atom, with the electron as the unit of electric quantity; these are all material and recoverable and unchangeable quantities, and are those in which our present units will be recorded never to be lost or destroyed, but even if they were it would not undo all that has been given to us by Kelvin the Measurer.

Silvanus P. Thompson—The Teacher.

It must, I think, have been in 1884 when first I saw Silvanus P. Thompson. I was a student in the evening classes of Finsbury College at that time and I remember one evening in the laboratory Professor Ayrton conducting round what struck me then as a small and precise gentleman who asked many questions, and whom I afterwards learned was Silvanus Thompson, then Professor of Electricity in Bristol University. That was his first visit to the College of which he afterwards became the Principal, and of which he was Principal when he died. But I am plunging into the middle. The ancestors of Silvanus Thompson were a Westmorland family of Morland, and his grandfather was, first, grocer and later banker of Appleby. It is interesting to observe that there is good evidence for thinking, from an observation of the family crests, that Silvanus Thompson and William Thomson were descended from a common ancestor. For some generations the Thompsons were Quakers. His father Silvanus Thompson, born at Appleby, unable because of his Quaker belief to enter Oxford or Cambridge, studied at University College, London, and became Master of the Quaker School for Boys in York in 1841 and in 1848 married a Tatham of Settle. Silvanus Thompson was the second child and was born in 1851. He early developed a taste for scientific experiments and his younger sister Maria was the dog on whom he experimented. Besides contriving cranes in which she was lifted—and, it may be added, not infrequently dropped—he had heard or read in a book of travels of the process of tattooing and in the nurse's absence had tattooed a star on his sister's wrist, rubbing in ashes from the fire-place. The result could be seen 40 years later.

In 1858 Silvanus Thompson entered Bootham School, a Quaker school, where he became a contributor to the school magazine, one of his first contributions being an article on electricity. At the age of 16 he sat for the London matriculation examination and in the same year entered the Quaker Training College at Pontefract, and in 1869 he obtained the B.A. degree of London University. In 1870 he took a post as junior master at Bootham School and thus began his teaching career. In 1875 he left this school and came to London, having gained a bursary at the Royal School of Mines, and during this time he attended lectures at the Royal Institution and other learned Societies. In 1876 he conducted with Dr. Guthrie some electrical researches which were communicated to the Royal Society in that year. It was in 1876 that, after he had applied for the post of Professor of Chemistry at Bristol, which he did not obtain, he applied for the lectureship on Physics and was appointed to the post, and in 1878, when a Chair of Physics was established, he was elected to the professorship and in the same year took his D.Sc. degree in London. It was now that he, having made a reputation as an investigator and as a lecturer, began his studies in the subject of technical education. He devoted several vacations to studying on the spot the technical and scientific educational systems of France, Germany and Switzerland, and his first public contribution to the subject was at the Social Science Congress at Cheltenham in 1878 on "Technical Education; where it should be given." He worked tremendously at this time on this subject, whilst at the Bristol University he was leading a most difficult and distasteful life. The funds of the college did not allow any real outlay on scientific apparatus. In 1880 he wrote: "My opportunities for working in physics are terribly circumscribed. My lecture room is used for all sorts of other lectures. My only laboratory is a damp cellar 11 ft. by 9 ft., etc." In 1880 he gave the inaugural lecture at the Mechanics' Institution, Nottingham, afterwards published as a pamphlet entitled "The Apprenticeship of the Past or the Future, or Trade Education for the Working Men of Nottingham." It was in 1880 that he began writing his book on Electricity and Magnetism, and in 1881 he married. In 1882 the University College, Bristol, came under new management and at last proper laboratories were fitted up under Thompson's guidance. Nevertheless, the opportunities for teaching science in the way he had conceived it should be taught were very limited, and it is not surprising that he was looking for much more extended opportunities for developing his ideas. He had been consulted by the City and Guilds Institute on the subject of a scheme for the Central Technical College, many of the ideas he put forward being embodied in the College which was opened in 1884. In 1885 when Professor Ayrton, then the Principal of Finsbury College, removed to the Central College Thompson was invited with others to apply for the post. This he did, and in 1885 at the age of 34 he became the Principal. He remained and worked there for 31 years. It was not a light task which he undertook. He was

Principal and Professor, Administrator and Teacher, often giving 10 lectures a week in the busy months. Finsbury College has held a unique position in education. The College did not prepare students for any degree or examination, but at the end of the courses gave certificates of proficiency, and these soon became a passport for good posts in the engineering world. "The laboratory, the workshop, and the drawing office take up the main portion of the student's time; for every hour in which the student is being talked to in the lecture room there are two hours in which he is instructing himself by actual work." These are his own words.

But I ought to have referred earlier to his first great electrical educational work—his "Elementary Lessons on Electricity and Magnetism." This he wrote in 1881, the year of the great Electrical Exhibition in Paris, the year when the electric light burst upon an astonished Europe. The book was an instantaneous success. In 1882 a second edition was called for, within two months his publishers warned him to prepare for a reprint, and in 12 years 16 reprints were necessary. This book was the cause of my first personal touch with Thompson. I had read in it an account of the effect of an iron case in shielding the space inside from magnetic effects. I was then 19 and was making many electrical and magnetic experiments. I suspended a needle and mirror inside a mustard tin with a narrow slot through which the light beam passed. I found very little shielding effect, so I wrote to Professor Thompson, at the same time pointing out three errata in the elementary lessons. The reply is from the Isle of Arran, and is as follows:

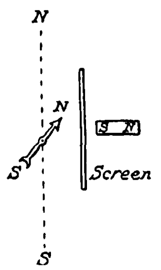
North Bank, Whiting Bay,
Isle of Arran, N.B.
7th August, 1882.

Dear Sir,

In my "lessons" I have certainly said that a sheet (not a "thin sheet" as you say) of iron will act as a magnetic screen, and it is quite true, though the thickness has a good deal to do with the perfectness of the action.

Sir W. Thomson used hollow iron bomb-shells to screen his marine galvanometers from external action on board cable-laying ships. Quarter-inch sheet iron I find to answer very well.

Common sheet tin acts as an *imperfect* screen but sufficiently perfect to get some curious results. For example, set a compass needle in the meridian. Then place a big bar magnet at one side so as to attract the needle into an oblique position. Then interpose a sheet-iron screen. You will see the deflection decrease (with two magnets and two screens, one on each side, the effect is more marked); and if you arrange things carefully you can get your needle to *rotate* by pulling in the screen at the right moment and pulling it out at the right moment. This I have often done with sheet tin.



For your errata pray accept my thanks. Two of the three were already marked for correction in the forthcoming new edition. You will, I believe, always find the authors of scientific books *most grateful* for information as to errata which, whatever pains one may take, *will* creep in.

I am, my dear Sir,
Yours faithfully,
Silvs. P. Thompson.

Ll. B. Atkinson, Esq.

That letter was a lesson which I have endeavoured to absorb and work to all my life. I was young and absolutely unknown to him, and yet on his holiday he took the trouble to spend his time in replying fully and helpfully. I have learned since that this was only one of countless similar cases.

In 1883 he delivered a course of Cantor lectures at the Society of Arts on "Dynamo-Electric Machinery." They created the greatest enthusiasm. I attended one of them and of course when published read the rest. It was the interest and demand for republication that was the starting-point of Thompson's "Dynamo-Electric Machinery." It has been written: "If Professor Thompson had done nothing else, this invaluable work would serve as his enduring monument." The book contained much original work, but its great success was due to his way of discussing with every inventor, designer and constructor his designs and ideas, and then by his great analytical and synthetic power rebuilding the whole structure, fitting each of these independent elements into its place as a whole. This work revolutionized dynamo design; it shortened by a decade the time taken to reach a definite point, and spread throughout the whole world in a simple way a knowledge of a subject until then wrapped in much obscurity to all except a few minds.

In the Silvanus P. Thompson memorial lecture in 1918, Sir Ernest Rutherford said:

"I gained my first knowledge of electricity from 'Elementary Lessons,' that remarkable and perennial book which has served to interest and instruct scientific youth and even middle age in all parts of the world.

"This work is marked by that clearness, simplicity and charm which is so characteristic of all his writings and lectures. If I was suckled, so to speak, on 'Elementary Lessons,' I cut my first teeth on 'Dynamo-Electric Machinery,' and I can well recall the strong impression left on me by the exceedingly clear, simple and logical statement on the essentials of a complex subject."

Of his other published works and notably of his Cantor lectures, and later his book on the electromagnet, I can only just speak. His lectures all over the world, his some 20 printed works, his personal teaching of the thousands of students who passed through his college and laboratory courses, always bringing not only his own knowledge, but the work of others, in a style, a lucidity, and a clarity that made the most difficult subject easy, these are what I stress as entitling him among our electrical men to the name of the great teacher, and alone and beyond that the great lesson which is mentioned on the memorial card issued by his family after he was gone, reminding all his past friends and students of "That best portion of a good man's life, his little nameless and unnumbered acts of kindness and of love."

And now I shall go back a little to the four great men whose work I have briefly sketched. What had they in common; in what did they differ?

Faraday the discoverer came of Yorkshire stock, and Thompson of Westmorland and Yorkshire stock. Kelvin and Maxwell were of Scottish stock. It seems as if south of the Tweed these philosophers are not born. Is the reason climatic? Is it something in the harder life of these northern parts, or the longer winter evenings which tend to books and studies, or is it that the races are different, the northern race having more insight into things unseen?

Again, we have seen that Faraday did not develop any special scientific bent of mind until his early youth, but in the case of Kelvin, of Maxwell, and of Thompson there were very early signs of their great scientific and mathematical ability.

Another point on which Maxwell and Kelvin had a common feeling of certainty was the finite age of the universe.

First, we shall take Maxwell's view. In a British Association Address in 1873 he said: "Each molecule therefore throughout the universe bears impressed upon it the stamp of a metric system as distinctly as does the metre of the Archives of Paris, or the double royal cubit of the Temple of Karnal. No theory of evolution can be formed to account for the evolution of molecules, for evolution necessarily implies continuous change, and the molecule is incapable of growth or decay, of generation or destruction. None of the processes of Nature since the time when Nature began has produced the slightest difference in the properties of any molecule. We are therefore unable to ascribe either the existence of the molecule or the identity of their properties to any of the causes which we call natural. On the other hand, the exact equality of each molecule to all others of the same kind give it, as Sir John Herschel has well said, the essential character of a manufactured article, and precludes the idea of its being eternal and self existent. . . . But in tracing back the history of matter, science is arrested when she assures herself on the one hand that the molecule has been made, and on the other that it has not been made by any of the processes we call natural. Science is incompetent to reason upon the creation of matter itself out of nothing. We have reached the utmost limit of our thinking faculties when we have admitted that because matter cannot be eternal and self-existent it must have been created."

Now how was Kelvin guided to this point?

One of his earliest enthusiasms in study was the work of Fourier, the mathematical physicist, who had shown how, given a certain distribution of heat in a material system, to calculate the flow of heat by conduction, and the consequent heat condition at any determined subsequent time. He had proved that, whilst the theory of Fourier enabled one to predict the future distribution from some existing distribution, it is not equally true to say that one can work backwards from any given distribution to a pre-existing distribution. In fact, we usually start with an arbitrary distribution which cannot have resulted by heat flow from any preceding distribution. Reasoning on these lines he came to the conclusion that the existing order of events could be traced back, if one had the necessary data, to a time zero, but not beyond, and, accepting the permanence of the atom, he concluded these must have had a beginning. In 1906 he was still opposing the views of the new chemistry and physics on the causes of radio-activity attributed to the breaking up of atoms and the production of new elements. But we may well learn to keep an open mind in scientific matters like this, for we now know of certainty that, contrary to Maxwell's views, there is evolution of the elements and of the atoms, and presently we may learn of a process of continuous creation.

Of the relation of these men to our Institution I may say a last word. Faraday died before our Institution was founded. Maxwell died while it was still the Society of Telegraph Engineers. Kelvin was President in 1874, and again in 1889, the year after its reconstruction as the Institution of Electrical Engineers, and for the third time in 1907, the year of his death, although he gave no Address nor took any part in the work of the session. Thompson was President in 1899; his Address was devoted to the subject of the future work and development of the Institution and, writing in later years, Dr. Alexander Russell said "much of the advice given in it has been adopted by our Institution."

Now I reach the end of this brief address, in which I have endeavoured in some way to co-ordinate those parts of the work of these great lights which relate to electrical work. If I have succeeded in any way in bringing to your minds what we owe to the work of these four men, perhaps to the point that you yourselves may pursue it further, I shall have achieved what I desired.