PRESIDENT'S ADDRESS.

The Development of Electrical Science.

By Thomas Gray.

In a brief discourse on the development of electrical science, little time can be given to the early history of the subject. This part is more or less familiar to all the members of the academy, and hence it may be passed over by only such brief reference as may serve to recall to mind the more important of the early discoveries. The early Greeks have recorded some elementary phenomena now known to be electric, and it is probable that such knowledge was not uncommon, though little noticed. It is only in comparatively recent times that scientific research has taken the place of superstition, and attempts have been made to classify and find reasons for the existence of all natural phenomena.

Beginning with the seventeenth century, probably the first investigator worthy of notice in this subject was Gilbert of Colchester, who published his work entitled "De Magnete" in 1600. Gilbert made systematic experiments and showed that the property of attracting light bodies could be given to a large number of substances by friction. He also showed that the success of the experiment depended largely upon the dryness of the body. These experiments gave rise to the classification of substances as electrics and non-electrics. The true effect of Gilbert's observations as to the effect of moisture was not appreciated for a long time. Gilbert's list of electrics was added to by a number of other observers, prominent among whom was Boyle and Newton. The fact that light and sound accompanies electric excitation was called attention to by Otto Von Guericke, who also showed that a light body, after being brought into contact with an electrified body, was repelled by it.

Coming now to the eighteenth century, we find Hawkesbee in 1707, and Wall in 1708, speculating on the similarity of the electric spark and lightning. Then comes one of the most prominent experimenters of this century—Stephen Gray—who began to publish in 1720, and who in 1729 found that certain substances would, and others would not, convey the charge of an electrified body to a distance. These experiments were the first to introduce the distinction between conductors and non-conductors, and, of course, very soon served to explain the reason why certain substances could not be electrified by friction when held in the hand. Gray also made the important discovery that the charge of an electrified body is proportional to its surface, and this was afterward confirmed by the experiments of Le Monnier. Many of Gray's experiments were repeated and extended by DuFay, who found that all bodies could be electrified by friction if they were held by an insulating substance. Then came the improvements of the electric machine by Boze and Winckler; the firing of inflammatory substances, such as alcohol, by means of the electric spark by Ludolph, Gordon, Miles, Franklin, and others. About this time (1745) the properties of the Leyden jar were discovered by Kleist, Cuneus, and Muschenbroeck; and a few years later it was given practically its present form by Sir William Watson. Then follows one of the periods of exceptional activity in electrical research. A party of the Royal Society, with Watson as chief operator, made a series of experiments having for their object the determination of the distance to which electrical excitation could be conveyed and the time it takes in transit. They found, among other things, that several persons at a distance apart might feel the electric shock if they formed part of a circuit between the electrified body and a conductor, such as the earth. Also, that the earth could be used to complete the circuit in Leyden jar discharges. They concluded that when two observers connected by a conductor and at, say, two miles apart, obtained a shock by one touching the inside coating of a Leyden jar and the other the earth, the electric circuit was four miles long; that is, the earth acted as a return conductor. They also concluded that the transmission was practically instantaneous. Watson had ideas as to electric fluids similar to those which were afterward systematically worked out by Franklin. A great many curious and interesting experiments were made about this time; as, for example, the influence of electrification on the flow of water through capillary tubes as discovered by Boze; the experiments of Mowbray on the effect of electrification on vegetation, and those of the Abbe Monon on the loss of weight of animals when they were kept electrified for a considerable time. The effect of electrification on the flow of water has received considerable attention from eminent authorities in recent years, and that of the effect of electrification on the growth and composition of vegetables is at present attracting attention in the form of systematic investigation.

The contributions by Franklin are by far the most important which mark the middle portion, or indeed any portion, of the eighteenth century.

Franklin's experiments were begun about the beginning of the year 1747, and seem to have been inspired by the receipt of a Leyden jar from a friend, Mr. Collinson, of London. He propounded the theory of positive and negative fluids, which has lately, in a modified form, been brought so prominently into notice by the writings of Lodge; and he made an investigation of the principle of the Leyden jar, but the most important of his researches relate to the identification of electricity and lightning. The probable identity of the two phenomena had been hinted at, as we have seen, by several observers, but Franklin went systematically to work to test the hypothesis. Under date November 7th, 1749, the following passage is found in his note book:

"Electric fluid agrees with lightning in these particulars: (1) Giving light; (2) Color of light; (3) Crooked direction; (4) Swift motion; (5) Being conducted by metals; (6) Crack or noise in exploding; (7) Subsisting in water or ice; (8) Bending bodies in passing through; (9) Destroying animals; (10) Melting metals; (11) Firing inflammable substances; (12) Sulphurous smell. The electric fluid is attracted by points; we do not know whether this property is in lightning, but since they agree in all the particulars wherein we can already compare them, is it not probable they agree likewise in this? Let the experiment be made."

The hypothesis was elaborated and sent to his friend Collinson, who communicated it to the Royal Society. This Society rather ridiculed Franklin's idea at first, but his paper was published in London and also in France, and attracted considerable attention.

The experiment was first made in France by M. d'Alibard, at Marle, on May 10th, 1752, and repeated shortly afterward by M. de Lor, in Paris. The results of what were called the Philadelphia experiments were communicated to the Royal Society and caused quite a stir in scientific circles. It is right to say with regard to the Royal Society, that Franklin's claims to scientific recognition were championed by Sir William Watson and were fully indorsed by the Society by Franklin's election to fellowship and the award of the Copley Medal, together with the free donation of the Society's transactions during his life.

Franklin's own experiments with kites are well known, as is also the method of protecting buildings from lightning, which was introduced by him and is still very widely used, although it has been greatly abused by the lightning-rod man.

During the next decade Canton discovered the now commonly known difference between vitreous and resinous electricity. Beccaria experimented on the conducting power of water. Symmer made a number of experiments on the electrification of different kinds of fabrics by friction, and propounded a theory of two electric fluids. Contemporaneous with these were a number of other experimenters who added to the stock of knowledge of this class of phenomena.

The experiments of Aepinus and others on the pyroelectric properties of tourmaline now began to attract attention. The experiments of the Abbe Haüy are perhaps the most important in this connection at this stage of the subject. He found the polar properties of the crystal and showed that similar properties are possessed by a number of other crystals. Aepinus made experiments in other branches of electricity, but he is chiefly noted for his ingenious single fluid theory of electricity.

Between the years 1770 and 1780, the electric organs of the torpedo was one of the principal topics of discussion. The experiments of Walsh and Ingenhousz were the first to settle definitely the character of the peculiar power of the fish.

The experiments of Cavendish belong to this period and were remarkable as being quantitative in their character. Considering the means at his command, the measurements made by this experimenter of the relative conducting powers of various substances must always excite admiration. Cavendish also proved the composition of water by causing different proportions of oxygen and hydrogen to unite by means of the electric spark.

We now come to the classical experiments of Coulomb, who established the law of the variation of the electric force with distance to be that of the inverse square: a law which had previously been inferred from experiments on spheres by Dr. Robinson, who, however, did not publish his results. Coulomb made an elaborate series of experiments on the distribution of electricity over charged conductors as influenced by shape and the proximity of other charged bodies. His theoretical and experimental work formed the basis of the mathematical theory as developed shortly afterwards by Laplace, Biot, and Poisson; the work of the latter being particularly important.

Toward the end of the eighteenth century were made the important researches of Laplace, Lavoisier, and Volta, and of Sausure on the electricity produced by evaporation and combustion. This is a subject destined to figure prominently again in the future; and in its rise there is in all probability involved the rapid decline in the importance of the steam engine. I should not be surprised if many of those present should live to see the steam engine practically a thing of the past. To the eighteenth century also we must assign the discovery of galvanic electricity, as the famous frog experiments were made in 1790; practically, however, no development was made until Volta's work attracted the attention of the scientific world. At the beginning of the nineteenth century, then, we find the subjects of greatest interest were the discoveries of Volta and the invention of the voltaic pile. Then followed almost immediately the discovery of Nicholson and Carlisle of the decomposition of water by the voltaic current. This discovery was followed a few years later by the discovery of Sir Humphrey Davy of the decomposition of the alkalies and the separation of metallic sodium and potassium. Thus the subject of electrolysis was fairly launched, and what it has grown to we will see later.

Can there be some inter-relation between electricity and magnetism was now the query. The first positive answer seems to have been given by Romagnesi in a work published in 1805, but little or no notice appears to have been taken of this; certainly no progress was made in the subject till 1820, when Oersted made his famous experiment before his class. By that experiment he proved that a wire carrying an electric current will, when properly placed, deflect a magnetic needle. The subject was almost immediately taken up by Ampere, and in a few months many of the important consequences which Oersted's discovery involved were developed. Ampere's work on the action of currents on currents and on magnets, is classsical and is still treated as part of the fundamental basis for the theory of electro-dynamics. An account of his work may therefore be found in almost any of the numerous text-books on electricity. The conclusions reached by Ampere were confirmed by Weber, by a series of much more refined experiments. To Weber also we owe improvements in galvanometers. The same year marks the discovery by Arago that a current can not only deflect a magnet, but that it is capable of producing one by magnetizing steel needles. The further discovery was made four years later by Sturgeon that soft iron, although incapable of making a strong permanent magnet, is much more susceptible to magnetization by the electric current. Arago also made about this time the important discovery that if a needle be suspended above a copper disc and the disc rotated, the needle will be dragged round with the disc. This was not explained for some years, but seems to have been the first discovery of induced currents.

These experiments mark the discovery of electro-magnetism and begin one of the most important eras in electrical discovery, and one in which many eminent authorities participated. Among the many advances may be mentioned the experiments by Henry on the relative effects of different windings on the strength of an electro-magnet. He deduced the fact that the magnetizing action might be increased either by increasing the number of windings, the current remaining the same; or by increasing the current, the windings remaining the same. He pointed out the application of this to intensity and quantity arrangement of the battery, and also the importance of the intensity winding for the transmission of magnetizing power to a distance, as in telegraphy. The increased effect due to increasing the number of windings on the coil of a galvanoscope had been previously pointed out by Schweigger, and the discovery is embodied in Schweigger's galvanoscope.

In 1821, Faraday began his researches and many important discoveries were made by him. The main guiding idea in Faraday's work was the possibility of obtaining electricity from magnetism, and in general the discovery of the inter-relation between the two. In this connection, Arago's discovery of the rotation of a copper disc by the rotation of a magnet above it is of great importance, because among other things Faraday set himself to explain this. The result was the discovery of the commutatorless dynamo or Faraday disc. In view of modern developments, probably the most important of Faraday's discoveries was that of the production of a current in a circuit when a current is either established or varied in strength in an adjacent circuit. This was followed by the discovery that relative motion of two circuits, one of which carried a current, poduced a current in the other, and that the motion of a magnet in the neighborhood of a circuit produced a current in the circuit. Another important discovery by Faraday was that of the quantitative laws which govern electrolytic decomposition, thus giving us our electro-chemical equivalents.

At this time Lenz was led by experiment to the discovery of his celebrated law of induction, namely, that the current produced always in turn produces forces tending to oppose the change. For example, if a current be induced in a coil by bringing a magnet toward it, the mutual action between the magnet and the current is to oppose the magnet's approach. This is important when looked at from the point of view of the conservation of energy, or as an argument against perpetual motion. Lenz's law is, of course, when the actions are properly understood, a consequence of Newton's third law of motion.

Discoveries similar to those of Faraday as to induced currents were made almost simultaneously by Henry in this country. We have in the discoveries of Faraday and Henry the fundamental information required for nearly the whole of our recent developments in dynamo-electric generators and electric motors, but it was reserved for the next generation to develop them. This development we owe in no small degree to the splendid exposition of Faraday's discoveries and their consequences, contained in Maxwell's book on electricity and magnetism.

Going back for a minute to 1822, we have to notice another important discovery; namely, the thermo-electric couple by Seebeck. There followed almost immediately the important experiments of Cumming, who showed that the thermo-electric order of the metals is not the same at all temperatures. The next important discovery in thermo-electricity was that by Peltier of the heat generated at the junction of two metals when a current is formed across it against the e. m. f. of the junction. In later years we have the classic researches of Thomson (Kelvin), who added thermo-electric convection and the specific heat of electricity, and gave the thermo-electric diagram method of representing results. This method was afterward used and extended by Tait, who added a good deal to our knowledge of thermo-electric data. Among the large number of others who have worked in this field, we may mention Becquerel, Magnus, Matthieson, Leroux, and Avenarius. Thermo-electric batteries of considerable power have been made by Clamond and others.

In 1827 the celebrated law giving the relation between e. m. f. resistance and current was published by Ohm in a paper on the mathematical theory of the Galvanic circuit. The theory has been sometimes criticised, but it seems to be absolutely certain that the law is almost exact, and it has proved to be of the greatest importance in the further development of the subject of electric measurements. The subject had, about the middle of the century, reached a stage in which it was possible to develop almost completely the mathematical theory as we now have it. Most of the work since Faraday's time has been largely directed toward quantitative measurements and the furnishing of exact data to answer questions as to *how much* in various cases. F. E. Neumann discovered what he called the potential function (now called the coefficient of self and mutual induction) of one current on another and on itself, and succeeded in giving a theory of induction which was in accordance with the experimental laws. The laws were afterward experimentally verified by Weber. In 1849 the experiments of Kirchhoff on the absolute value of the current induced in circuit by another, and in the same year Edmund's experiments on self and mutual induction, are important. In 1851 Helmholtz gave a mathematical theory of this part of the subject which he supplemented with an experimental verification.

One of the most important of the series of experiments made by Henry was on the oscillatory character of the discharge from a Leyden jar. This he discovered from the effect of the discharge on a steel needle surrounded by a coil through which the current was made to pass. The results of these experiments were communicated to the A. A. A. S. in 1850, but he knew of the effect much earlier, certainly in 1842. Previously the anomalous behavior of the discharge of a jar when used to magnetize steel needles had been noticed, but was attributed, I believe, to some peculiarity of the steel. Henry was the first to appreciate the true reason, although he could hardly at that time be expected to see the great importance of his discovery.

Helmholtz in 1847 suggests that the discharge of Leyden jars may be of the nature of a backward and forward movement. There is a curious parallelism in the work of several investigators about this time, and particularly in that of Helmholtz and Thomson. In the Philosophical Magazine for 1855 there is a paper by Prof. W. Thomson (Kelvin) in which the theory of the discharge of a Leyden jar is discussed and the prediction made that under certain specified conditions the discharge must be oscillatory. A number of similar papers going back to 1848 treat of similar subjects. Henry's results do not appear to have become generally known, and we find the verification of Thomson's prediction in 1857 by Feddersen. A number of other physicists have investigated the subject, the work of Schiller being of particular value. The recent applications will be referred to later.

The mathematical theory of electrostatics and magnetism was greatly extended about this time by Thomson and others, and received its most complete statement at the hands of Maxwell in his papers read before the Royal Society and in his book published in 1873, still the standard of reference. Very little has since been discovered which was not foreshadowed by Maxwell's theory or contained in his equations which have been found general enough to cover almost everything, although experiment has generally been necessary to suggest the consequences of the theory.

The practical applications of electricity have played a most important part in the development of the subject in the last sixty years. Indeed, a great part of the work of these years has had some practical application in view. One of the first of these practical applications was that of telegraphy. The telegraph, being one of the earliest of the practical developments, naturally had a great effect in stimulating the advance in knowledge of electricity, and hence I give a somewhat fuller sketch of the early history than space will permit for the later applications. The discovery of Stephen Gray in 1729, that the electrical influence could be conveyed to a distance by means of an insulated wire, is probably the first discovery of direct influence in connection with telegraphy. As a result of this discovery and the investigations which followed it, a considerable number of proposals were made as to the use of the electrical force for the transmission of intelligence. The first of these of which I have found any record was made in 1737 by Charles Morrison, a Scotchman, and there followed other proposals for electrostatic telegraphs by Bozolus in 1767, Le Sage in 1774, Lomond in 1787, by Betancourt in the same year, by Reizen in 1794, Cavallo in 1795, and by Ronolds in 1816.

The discovery of voltaic electricity, and most directly the discovery by Nicholson and Carlisle of electrolysis, gave rise to another group of proposals for the application of this discovery to the production of a telegraph. Among those may be mentioned that of Sömmering in 1809, of Coxe in 1810, and of Sharpe in 1813. In more recent years of course the same application appears in the chemical telegraphs, some of which are capable of giving very satisfactory results and great speed.

The discovery which had the greatest influence on the development of telegraphy was that of Oersted, supplemented by the work of Schweigger and Ampere. Ampere proposed a multiple-wire telegraph with galvanoscope indicators in 1820, and a modification was constructed by Ritchie. A single circuit telegraph of this character was invented in 1828 by Tribaoillet, but did not come into use. In 1832 Schilling's five-needle telegraph appeared, and he also used a single-needle instrument; but his early death stopped further progress. In 1833 Schilling's telegraph was developed to some extent by Gauss and Weber, who used it for experimental purposes. The following quotation referring to Gauss and Weber's telegraph, from Poggendorf's Annalen, is of considerable historical interest:

"There is, in connection with these arrangements, a great, and until now in its way novel, project, for which we are indebted to Professor Weber. This gentleman erected during the past year a double-wire line over the houses of the town (Gottingen) from the Physical Cabinet to the Observatory, and lately a continuation from the latter building to the Magnetic Observatory. Thus an immense galvanic chain is formed, in which the galvanic current, the two multipliers at the ends being included, has to travel a distance of nearly 9,000 (Prussian) feet. The line wire is mostly of copper of that known as 'No. 3,' of which one meter weighs eight grammes. The wire of the multipliers in the magnetic observatory of copper 'No. 14,' silvered, of which one meter weighs 2.6 grammes. This arrangement promises to offer opportunities for a number of interesting experiments. We regard, not without admiration, how a single pair of plates, brought into contact at the further end, instantaneously communicates a movement to the magnetic bar, which is deflected at once for over a thousand divisions of the scale." Further on in the same paper: "The ease with which the manipulator has the magnetic needle in his command, by means of the communicator, had a year ago suggested experiments of an application to telegraphic signaling, which, with whole words and even short sentences, completely succeeded. There is no doubt that it would be possible to arrange an uninterrupted telegraph communication in the same way between two places at a considerable number of miles distance from each other."

The method of producing the currents in Gauss and Weber's experiments was an application of the important discoveries of Faraday and Henry above referred to, in the induction of current by currents and by magnets. On the recommendation of Gauss the telegraph was taken up by Steinheil who, following their example, also used induced currents. The important contributions of Steinheil were the discovery of the earth return circuit, the invention of a telegraphic alphabet and a recording telegraph. Steinheil contributes an account of his telegraph to Sturgeon's Annals of Electricity, in which the relative merits of scopic, recording, and acoustic telegraphs are discussed; and the advantages, which experience has since brought into prominence, of the acoustic form is pointed out.

Schilling's telegraph was exhibited at a meeting of German naturalists held at Bonn in 1835, and was there seen by Prof. Muncke of Heidelberg, who, after his return to Heidelberg, made models of the telegraph and exhibited them in his class room. These models were seen by Cooke in the early part of 1836, and gave him the idea of introducing the electric telegraph in England. Cooke afterward became associated with Wheatstone, and a large number of ingenious arrangements for telegraphing was the result. Many of the later developments by Wheatstone are still in use and are hard to beat.

Steinheil appears to have been anticipated in the idea of making the telegraph self-recording by Morse, who, according to evidence brought forward by himself, thought out some arrangements as early as 1832. Exactly what Morse's first ideas were seems somewhat doubtful, and he did nothing till 1835, when he made a rough model of an electro-magnetic recording telegraph. Morse's mechanical arrangements were of little merit and his alphabet and method of interpretation by a dictionary was clumsy and inconvenient. The chief point of interest in connection with the early history of the Morse telegraph was the proposal to make use of Sturgeon's discovery of electro-magnetism of soft iron. Morse, however, seems to have known practically nothing of the subject except that iron could be magnetized by a current, and in consulting his colleague, Dr. Gale, he was unwittingly led to use the discoveries of Henry who had previously practically solved the whole problem. Much of the subsequent improvements in the mechancial arrangements were due to Vail, who became associated with Morse, and the Morse code as we now know it was almost, if not entirely, worked out by Vail. Considerable dispute and some litigation arose over Morse's claims, but that is outside our present subject. There is no doubt that the electric telegraph was a slow growth, inventors, with a view to pecuniary and other advantage, being ever ready to lay hold of each scientific discovery and try to turn it to account. The question, who first conceived the idea, can never be satisfactorily answered. After 1840 there is little to record of a purely electrical character bearing only on telegraphy, but there have been many very ingenious mechanical contrivances introduced for recording signals, for reproducing pictures and handwriting, and for printing, for duplexing, quadruplexing, and multiplexing telegraph lines, for increasing the rate of signaling, and in many ways increasing the expedition with which messages can be sent. Of course the success of many of these contrivances and even their invention depended on increased knowledge of the laws of electricity and magnetism. For example, effective duplexing, quadruplexing, etc., depends on a proper understanding of the effect of the electrostatic capacity of the line, and this was not understood properly until the mathematical investigations of Thomson and others cleared the matter up. For the impetus toward discovery in this direction, again, we are largely indebted to telegraphy, for much of that class of work was suggested by the difficulties encountered in signaling through long submarine cables.

The invention of the telephone is fast becoming ancient history, yet it will always mark one of the greatest of the useful applications of electricity. It does not call for more than a passing remark here, because electro-magnetically it is all in Faraday and Henry's papers. The radiophone should be mentioned because it marks the application of the discovery by May and Smith of the effect of light on the resistance of selenium. This effect has since been found in the case of a large number of other substances, but it is still an interesting field for research. A number of experiments on this subject have been associated with attempts to make things visible at a distance. No doubt it will ultimately be possible not only to talk to a distant party, but also to see the party talked to, and thus, as it were, look the party in the eye with whom you are conversing.

The subject of telegraphy is closely associated with the present excellent system of electrical measurements and with the invention of many of our most delicate measuring instruments. As the applications of electricity increased there gradually grew up a new branch of engineering, a branch, however, in which the foot rule, pound weight, chronometer and thermometer were not sufficient. Other standards of measurement were required in order that quantities could be gauged and consistent work done. The way to connect the measurement of the new quantities with the units already in use in dynamics had been pointed out by Gauss and others, and at the suggestion of Thomson the British Association appointed a committee in 1861 to determine the best standard of electrical resistance. This led to an unexpected amount of work, not only on a standard of resistance, but also on the general subject of electrical measurements. The committee regretted at the end of the first year that it could not give a final report, but hoped that the inherent difficulty and importance of the subject would sufficiently account for the delay. It can hardly be said that the final report has yet been forthcoming, as a committee with some of the original members in it still exists and reports regularly every year on valuable work done by it. The committee worked energetically for a number of years, not only on the standard of resistance, but on those of current, electro-motive force and capacity. It incidentally supplied a great deal of quantitative data on a number of subjects and particularly as to the permanency of alloys, the variation of their resistance with temperature as depending on their composition, and so forth. In looking over the results of the early work of the British Association committee one is apt to indulge in adverse criticism. It is hard for many of the younger workers to appreciate the difficulties which are met in a first attempt. It would be equally just to congratulate ourselves that we have better marksmen to-day than there were fifty years ago, without making allowance for the modern rifle.

The first absolute determination of resistance was probably that made by Kirchhoff about fifty years ago. Weber published his method in 1852, and then came the British Association's determination by Maxwell, Stewart and Jenkin in 1863. Neither of these were very exact, but they paved the way for the splendid exhibitions of experimental skill which followed. Among those to whom we are most indebted for this later work may be mentioned Kohlrausch, Rayleigh, Glazebrook, Rowland, Wiedemann, Mascart, etc. The greatest step in advance in recent years has been the invention of the revolving disc method by Lorenz of Copenhagen, and its subsequent improvement and application by himself and by J. V. Jones. The determinations made by the latter by this method are probably almost absolutely correct.

A subject which has attracted much attention comes in incidentally here, namely, the electro-magnetic theory of light propagation suggested by Maxwell. According to this theory the ratio of the electro-magnetic unit of quantity of electricity to the electrostatic unit ought to be the same as the velocity of light. In 1868 a determination of this ratio was made by McKichan under Lord Kelvin's direction and gave close agreement with the theory. Since that time determinations have been made by various methods by Maxwell, Shida, Ayrton and Perry, J. J. Thomson, Rosa, Lodge, Glazebrook and others, with the result that the ratio of the two units does not differ from the velocity of light by as much as the probable error of observation. The work here referred to may not appear to be very directly associated with the determination of standards of measurement. It is, however, one of the investigations which has been made possible by the work of the British Association committee in the production of instruments of precision. Prominent among these instruments stands the Kelvin electrometers and particularly the absolute electrometer which was described in the report of the British Association committee in 1867.

Another subject of great interest in itself and in connection with Maxwell's theory is that of the specific inductive capacity of dielectrics. Experiments on this subject were made by Faraday, but comparatively little was done before 1870, in which year an excellent paper was communicated to the Royal Society by Gibson and Barclay on the specific inductive capacity of paraffin. Since that time much good work has been done by Boltzmann, Hopkinson, Quincke, Silow, Klemencic, Negreano and others. The theoretical importance of these experiments is due to the fact that according to Maxwell's theory the specific inductive capacity of nonmagnetic dielectrics should be proportional to the squares of their indices of refraction. A wonderful verification of Maxwell's theory was carried out only some ten years ago by Hertz, who showed not only that electrical waves exist, but also how to measure their wave length and period. We have in these experiments splendid illustrations of the oscillatory discharge referred to above as discovered by Henry and predicted by Thomson, and as a result several new ways of determining electrical quantities have been developed. It is now possible, for example, to compare the capacity of condensers by means of oscillatory currents of exceedingly short period and thus to determine the dielectric constants of many materials to which the older methods were not easily applicable.

It is somewhat difficult to decide where to place a reference to the recent discovery of Röntgen and its developments in photography, but probably it comes in well here. Just how to apply Maxwell's equations to Röntgen's rays is not yet quite clear, but there is no doubt as to the great importance of the discovery.

As an outcome of all this activity in the determination of standards and in the absolute measurement of the electric properties of materials, combined with the great commercial demand produced by the introduction of dynamo machinery, we have now many excellent instruments at our disposal for absolute measurement and suitable either for practical applications or for the most refined laboratory work. For the production of these we are indebted to a host of inventors. Prominent among them may be mentioned Lord Kelvin, Lord Rayleigh, Ayrton and Perry, Mather, Swinburne, Cardew and Weston.

Magneto-electric and dynamo-electric generators and motors have now become so common that we are apt to forget that their introduction on an extensive scale has only taken a few years. Faraday's disc dynamo was, as has already been stated, produced in 1831, and a machine for generating electricity was made by Pixii in the following year. Pixii's machine consisted of a horseshoe permanent magnet, which was rotated in such a way that its poles passed alternately in front of the poles of a similar electro-magnet. An alternating current was thus induced in the circuit which included the coils of the electro-magnet. This machine was improved by Clarke, who revolved the coils and put a commutator on the axle. Other machines were made or suggested by various physicists, and an important observation, which has since been frequently overlooked, was made at this time by Jacobi, who pointed out the importance of making the cores of the coil short. Sturgeon in 1835 made a dynamo with a shuttle-shaped armature; a similar form has long been identified with the name of Siemens. Woolrich made a multipolar magneto machine in 1841 for electroplating, and Wheatstone about this time produced his small multipolar magneto long used for telegraph purposes. In 1845 Wheatstone and Cooke patented the use of electro-magnets in place of the permanent magnets, and Brett suggested in 1848 that the current from the machine might be made to pass round a coil surrounding the magnet and thus increase its strength. A similar suggestion was independently made in 1851 by Sinsteden. In 1849 Pulvermacher proposed the use of thin laminae of iron for the cores of the magnet, a proposition which has since, but probably for a different reason, been almost universally adopted. Sinsteden used iron wire cores and made a number of experiments on the effect of varying the pole face. About this time another class of machines was proposed by Ritchie, Page and Dujardin. In these machines both the magnets and the coils were to be stationary, but the magnetism was to be varied by revolving soft iron pieces in front of the poles. Modern representatives of these machines are to be found in the dynamos of Kingdon, Stanley and others. All the machines up to this time had been of very small dimensions, but in 1849 Nollet began the construction of an alternating machine on a larger scale, but died before it was completed. Machines of Nollet's type were afterward made by Holmes and by the Compagnie d'Alliance of Paris, the latter being called the Alliance machine. The machines were used for light-house purposes. Holmes's earlier machines were continuous current, but later he left out the commutator and still later again introduced it on part of the coils for the purpose of obtaining current to excite his field magnets. This latter plan was introduced after the self-exciting principle had been introduced by Siemens and by Wheatstone. A remarkable machine, historically, was patented in 1848 by Hjorth. In this machine a combination of the permanent and electro-magnet was used—the first to give magnetism enough to produce a current with which to excite the other. A similar idea was developed fifteen years later by Wilde with this difference, that the permanent magnet part was a separate machine. The idea of using part of the current from the armature to excite or partially excite the field magnets was at this time in the minds of a number of workers, and some remarkable machines were patented by the brothers Varley, one of which containing both a shunt and a series winding has been held by some to anticipate the compound winding now in use. In 1867 it seems to have occurred independently to Wheatstone and to Werner Siemens that the permanent magnet part of the Hjorth and Wilde machines might be dispensed with, the residual magnetism being used to start the action. Siemens gave the name dynamo-electric machine to this type, and it has stuck. In order to diminish the fluctuations in the strength of the current during one revolution of the armature, Pacinotti devised his multigrooved armature machine in 1864. This machine did not receive the notice it deserved for a number of years, and in the meantime Gramme produced his smooth-ring armature in 1870. Gramme's machine was soon recognized as being of great merit and its gradual introduction gave rise to increased activity. In 1873 the Hefner Alteneck improvements on the Siemens armature were introduced, and in the remaining 70's quite a number of forms of dynamos were invented, the Lontin type, introduced in 1875, with improvement in subsequent years, being one of the best. The early 80's saw tremendous activity. The patent offices in Europe and America were flooded with inventions of various types of dynamos and motors, of lamps for electric lighting, etc. It is curious how few of these machines have stood the test of time and how well the old types of

Pacinotti, Gramme. Siemens. Alteneck and Lontin in some one of their modifications hold the field. Great progress has been made in the last fifteen years. Machines have assumed enormous proportions, and the number of branches of industry to which they have been applied is now very large. Much has been learned during this time, particularly with regard to alternating currents and their application to the transmission of power, the introduction of multiphase systems being of considerable importance in this connection. In the direction of high potential and great frequency the work of E. Thomson and of Tesla is of great interest.

Of the application of electricity to the production of light and heat little need be said in this connection. The difficulties to be overcome were largely mechanical, and with the progress made we are all familiar. As regards primary batteries there has been, of course, as we all know, considerable progress since the time of Volta. The number of forms brought into use has been enormous, and they have been important in increasing our knowledge of the relative electro-motive force of various combinations and in their bearing on chemical knowledge. It can hardly be said that an ideal primary battery has yet been obtained when we look at the subject from a commercial point of view. Although the subject is not very much to the front at present, however, it is destined to come again, and I have no doubt it will be in a comparatively short time one of our leading industries. The work of Plantè and of Faure and others on secondary batteries has been of great value commercially. They gave rise to several chemical problems, but the main difficulty here also has been of a mechanical kind, and they have not added much to the knowledge of electrical laws.

The transformation of alternating current from high to low potential, and vice versa, by means of what are commonly called transformers, has shown another remarkable development of Faraday's discovery of induced currents. The application of transformers has made it possible to distribute electrical energy over large areas in a moderately economical manner and incidentally has led to considerable increase in the knowledge of the magnetic properties of iron. One of the most important of the applications of electricity is that of electro-chemistry. The chemical action of the electric spark was noticed by Von Groest and Dieman in 1739 in the decomposition of water. Becarri, about the middle of the eighteenth century, obtained metals from oxides through which the spark had passed, and in 1778 Priestley noted the production of an acid gas when the electric spark was passed through air. Similar experiments were made by Cavendish and Von Marum with decomposed ammonia. It is not, however, till after the discovery of the voltaic cell that the subject of electrolysis really begins. I have already referred to the discovery of Nicholson and Carlisle in 1800 and to the subsequent work of Davy and Faraday. The peculiar phenomena of the appearance of separated elements only at the end plates in the electrolytic cell led to considerable speculation and was explained by Grothuss on the supposition that the molecules separated into two parts, one positively and the other negatively electrified, and that these parts formed a chain between the plates along which chemical action traveled by a continual interchange of mates, the end parts going to the plates. This theory was held for many years and is still to be found in some text books. Faraday's work is by the far the most valuable of the early contributions to this subject. He gave the following laws:

"The amount of chemical decomposition in electrolysis is proportional to the current and the time of its action.

"The mass of an ion liberated by a definite quantity of electricity is directly proportional to its chemical equivalent weight.

"The quantity of electricity which is required to decompose a certain amount of an electrolyte is equal to the quantity which would be produced by recombining the separated ions in a battery."

These laws are all of the greatest importance, and the last one clearly points out the reversibility of the electrical process. By forcing a current through an electrolyte it is decomposed and the mutual potential energy of the components consequently increased. By allowing the components to recombine in a battery the mutual potential energy is reduced and a current of electricity is the result. An excellent illustration of this action is exhibited by the secondary battery.

In 1857 Clausius gave a theory of electrolysis and at the same time reviewed the weaknesses of the hypotheses of Grothuss and others. Clausius assumes that the molecules of the liquid are in continual motion, that impacts frequently occur which produce temporary dissociation, leaving atomic groups charged with opposite electricities, and that during these separations any directive agency such as an e. m. f. is able to cause a motion of these atoms in opposite directions. This is probably the first indication of the idea of the purely directive character of the applied electro-motive force, taking advantage of dissociation to produce chemical separation.

The energy side of the problem now began to attract attention and the development of what may be called the thermo-dynamics of electro-chemistry began. Among the most prominent workers in the field have been Joule, Helmholtz, Gibbs, Kelvin, Bosscha and Faure. In 1853 Hittorf made quantitative determinations of the change of concentration near the electrodes when a current is passed through a solution. His work is of historical interest because his work and conclusions formed practically the starting point for what may be called the modern view of electrolysis. Hittorf's experiments extended over several years and served practically to establish the theory of the migration of the ions in the solution. Hittorf communicated the following laws:

"The change in concentration due to current is determined by the motion which the ions have in the unchanged solution.

"The unlike ions must have different velocities to produce such change of concentration.

"The numbers which express ionic velocities mean the relative distance through which the ions move between the salt molecules, or express their relative velocities in reference to the solution, the change in concentration being a function of the relative ionic velocities."

Hittorf's analyses enabled him to give numerical values to these relative velocities. The experiments of Nernst, Loeb and others have extended Hittorf's results and have shown that in dilute solutions the relative velocities of the ions are independent of the difference of potential between the electrodes and are only slightly, if at all, influenced by temperature. Hittorf pointed out that a knowledge of the conductivity of electrolytes should give valuable information in reference to the nature of electrolytic action. A great deal of work has been done in this direction by Horsford, Weidemann, Beez, the Kohlrausches and others. The most notable, perhaps, was the work of F. Kohlrausch, who devised a method of measurement, using alternating currents, by which results of high accuracy were obtained. Kohlrausch's results give the sum of the ionic velocities, and thus combined with the results of Hittorf on change of concentration, which gave the ratios, the absolute velocities can be obtained. It appears from these results that the velocity of the ions in very dilute solutions depends only on its own nature and not upon the nature of the other ions with which it may be associated. For example, the velocity of the chlorine ion is the same when determined from solutions of K Cl, Na Cl or H Cl. The important general law has also been found that the conductivities of neutral salts are additively made up of two values, one dependent on the positive, the other upon the negative ion. If then the velocities of the ions themselves be known the conductivity of a salt may be calculated. The results of Kohlrausch received strong confirmation from some very ingenious experiments by Lodge and Wetham, in which the migration of the ions was made to produce a change of color in the solution and could thus be directly observed.

In 1887 the theory was advanced by Arrhenius and Ostwald that dissociation is directly effected by solution or fusion, and that in very dilute solutions the dissociation is practically complete. Arrhenius holds that the ions carry charges of electricity, positive or negative, dependent upon their nature, but of equal quantity in every ion. The remaining part of the theory is similar to that of Clausius and others. According to this theory the ratio of conductivities for different densities of solution gives a measure of the relative dissociation or ionization. If the act of solution affects the dissociation necessary to admit electrolysis, chemically pure substances ought not to be decomposed by the electric current, and this is found to be the case. It is curious that two substances like hydrochloric acid and water, which separately are insulators, should when mixed conduct readily, and that practically only one of them should be decomposed. This, however, is only one of the many problems still to be solved. Another question is, how do the ions obtain their electric charge? Still another, what is the nature of the force which causes ionization? There are many more.

When we turn to the commercial applications of electro-chemistry we are met with the astonishing evidences of activity. Only twenty years ago there was comparatively little evidence of the importance of this branch of applied electricity. At the electrical exhibition in 1881 electro-chemistry was apparently of comparatively little prominence. A factory which could annually produce a few hundred tons of copper electrolytically was considered a wonder. The production of thousands of tons a month is beginning to be looked upon as commonplace. There is scarcely a metal which cannot be deposited electrolytically with comparative ease, and the prices of some of the rarer metals are going down rapidly. Zinc used to be considered a difficult metal to deposit successfully. It is now produced in some of the Australian mines in almost a pure state from refractory ores at the rate of thousands of tons per annum. Similarly the old method of galvanizing is rapidly disappearing and electro-deposition is taking its place, and this metal is now so deposited on the hulls of ships, on anchors and other smaller articles cheaply and perfectly. A new industry has practically sprung up, and there is every indication that the technical chemist of the near future will have to take an inferior place unless he be also well versed in electricity and electrical appliances. This branch of applied science is revolutionizing many things. It has within a few years produced an enormous improvement in our magazine illustrations and has at the same time reduced the cost of this kind of literature and of atlases and charts enormously. Electro-chemistry is now used on a large scale for the production of bleaching materials, chlorate of potash, alkalies, coloring matters, antiseptics like iodoform, anaesthetics like chloroform, etc.—in fact, it is getting to be difficult even to enumerate the manufactures in which it is used. It has revolutionized the extraction of gold, and plants of enormous capacity are now in use in some of the gold fields, the poorest ores and tailings being made to yield up almost the last trace of the precious metal. The production of ozone by the ton, the purification of sewage, the sterilization of water are all accomplished facts. Some progress has even been made in the introduction of chemicals through animal tissue by electrolysis or cataphoresis, and Röntgen has shown us how to see through the body.

Then, again, we have got the electric furnace, and with it the power to fuse almost the most refractory substances. In this way aluminum is now produced at a few cents a pound, whereas most of us can remember when its price had to be reckoned in hundreds of dollars. In a similar way phosphorus is now produced on a large scale, as is also various carbides, carborundum, acetylene, etc.

It is impossible to look back over the history of electricity and its applications and notice the apparent geometric ratio in which advances are being made and not to speculate on what a giant this science is going to become in another quarter of a century. Undoubtedly no one can study this one branch of science without being persuaded of the great value of scientific work for the advancement of human enterprise.