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CERTAIN ASPECTS OF HENRY'S EXPERIMENTS ON ELECTROMAGNETIC INDUCTION[1]

By President JOSEPH S. AMES

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I REGARD it as a great honor to be invited to give the first of a series of lectures before the Washington Philosophical Society, to be known as the Joseph Henry lectures, established in honor of the founder and the first president of the society.

I think it is undoubtedly proper for me to choose as the topic of this first lecture one which is related to the life of Joseph Henry, partly because of the association of his name with the lectureship, but also because this year is recognized as the one hundredth anniversary of the discovery of the phenomena of electromagnetic induction, a discovery with which the name of Joseph Henry will always be associated.

This discovery of electromagnetic induction marked the beginning of the modern era of electricity and in fact of the modern era of physics, and it is therefore most fitting that a celebration of the centennial anniversary of the discovery should take place. Last month such a celebration was held in London at the Royal Institution, to commemorate the part Michael Faraday played in the discovery. Although he was anticipated in this by Joseph Henry, so far as both mutual induction and self-induction are concerned, Faraday will always be regarded, properly, I think, as their real discoverer because he was the first to publish the results of his investigations and pointed out at the time of his first announcement the possibility of making practical application of them. Joseph Henry, himself, although he deeply regretted the fact that he had delayed publication of his investigations,

[1] An address delivered before the Philosophical Society of Washington on October 24, 1931.

always gave full credit to Faraday and was scrupulously careful to refer to him as the discoverer. The newspapers, magazines and scientific periodicals have called attention repeatedly during the past two months to the work of Faraday and to his greatness as an experimenter and as a philosopher of nature. Rather scant notice has been given to the work of Joseph Henry, one writer saying that he "probably anticipated" Faraday; and my real reason for selecting the topic I have for this evening is my desire to impress upon all of you who listen to me the essential facts of Henry's great discoveries. Certainly whenever an American physicist hears the words, induced currents, the first thought that should come to his mind is "Joseph Henry discovered these."

It will indeed be superfluous for me to give a sketch of the life of Henry or to refer in detail to the long series of his brilliant investigations in the varied fields of physics or to his great contributions to the scientific life of this country. Any one who is interested in these matters should read the address by Professor William B. Taylor which was read before this society fifty-three years ago this month and which was published by the government in a volume devoted to the life and scientific work of Henry, and especially the excellent article by Professor Magie in the October number of *Reviews of Modern Physics*.

I intend to confine myself this evening to the question of induced electric currents and, even more narrowly, to the original experiments of Henry, calling attention particularly to the dates at which his discoveries were made. I must begin, however, by making as the background of my paper a statement concerning the scientific knowledge available at the time Henry began his experiments and also a description of Henry's environment, so that you may understand more clearly the stimulus which animated him and the difficulties under which he labored.

In 1819 Oersted made the discovery that an electric current flowing in a conductor exerted a force upon a magnet, and this great event was, of course, followed at once by investigations all over Europe. In the following year Schweigger devised his multiplier, consisting of an arrangement by which a magnetic needle came under the influence of several turns of wire, and thus perfected a rather sensitive instrument for the detection of an electric current. In this same year, 1820, Arago and Davy discovered independently that a steel needle placed axially inside a helix of wire became magnetized when an electric current was passed through the helix. In this experiment of Arago's the wire was uncovered and was wrapped in a loose helix around a glass tube, the needle being placed inside this tube. In the same year also Ampère began his brilliant series of studies on the action of currents on magnets and of currents on currents, resulting in the discovery of phenomena which form the basis of electrodynamics. In these experiments Ampère used single turns of bare wire. In 1825 William Sturgeon, of Woolwich, England, really developed the electromagnet by winding uncovered wire around an iron bar, which was insulated from the wire, the iron bar itself being bent into the shape of a horseshoe so that an armature could be placed across its two ends. In this electromagnet Sturgeon used eighteen turns, loosely coiled. These were the essential facts concerning the relations between electricity and magnetism known to the scientific world at the time Henry began his studies.

In 1826 Joseph Henry was elected professor of mathematics and of natural philosophy at the Albany Academy. This was one of the outstanding high schools of the State of New York, and the work done there compared favorably with that characteristic of some of the colleges of that day. He was twenty-seven years old at the time of his appointment, and his interests were already centered in the study of natural philosophy, his attention having been called to the subject when he was fifteen years old by the chance reading of a book which he had found left on a table by a man boarding with his mother. This book, Dr. G. Gregory's "Lectures on Experimental Philosophy, Astronomy and Chemistry," made a great impression upon the boy's mind, and it is recorded that the owner gave it to him and that he kept it with him throughout his entire life. It aroused his intellectual curiosity and inspired him with a desire to answer questions dealing with nature. He set to work at once to perfect himself for this life of investigation, and after some years of study, teaching and tutoring, during which time he presented several papers before the local scientific society, the Albany Institute, he was chosen unanimously to fill the position I have mentioned. Albany at that time was a small city practically on the frontier, remote from centers of scholarship or of study, but the Albany Academy was a very worthy institution. It occupied a large building in the center of the city, consisting of classrooms and one good-sized hall in its center, used for general purposes. There was no laboratory, of course, as such, and no apparatus of any kind; consequently, Henry had to do everything with his own hands except so far as he could call upon a blacksmith to help. Schools in those days were rather serious-minded institutions and Henry was kept fully occupied with his classes as long as the school was operating, which was for practically ten months of the year. The sessions began the first of September and during all the time Henry was professor in the academy the only opportunity he had for experimental investigations was during the summer vacations, and practically for only one month, the last part of

July and the first part of August. When the vacation began Henry would set up his apparatus in the main hall of the building and he could work with it until in August the time came for the building to be cleaned and gotten ready for the classes which met, as I have said, the first of September.

I must ask you to consider this situation and to contrast it with that of the investigators in Europe, especially of Faraday. Here was a man evidently full of ideas, evidently eager to add to knowledge and to test his theories by experiments; but he had no apparatus, he had no means to buy any even if it had been available and he had at his disposal only a few weeks of the year in which he could devote himself to what was really the purpose of his life. When one considers these circumstances it is extraordinary indeed that Henry should have been able to advance as far as he did.

Henry read with eagerness everything that was published in regard to the connection between electricity and magnetism and as soon as he became a professor at the Albany Academy he began to make plans for the continuation of the experimental work of which he had read. The first thing he planned to do, naturally, was to repeat the work of others so as to convince himself of its accuracy and to become more familiar with the phenomena. In thinking over the experiments done by others he believed that he could increase the sensitiveness of the apparatus and could magnify the forces by an extremely simple device, which apparently had not occurred to any one else. This was to use coils of insulated wire in place of single turns, and in October, 1827, he demonstrated before the Albany Institute the various experiments of Ampère and others, using coils and thus magnifying the effect greatly. In order to superimpose one layer of the coil upon another layer, thus forming a bobbin, it was obviously necessary to insulate the wire itself, which he did by wrapping the wire "with silk," as he says. I have heard from the family that "the silk" used by Henry in making some of his first coils was really a series of ribbons of silk obtained by the sacrifice on the part of his wife of her white silk petticoat. An electromagnet made by Joseph Henry and used in his experiments is still in existence, being treasured in the museum at Princeton University, and one can still see the white silk ribbons used in its construction, so I believe the story I have heard is true.

One can hardly overestimate the importance of this device of Henry's. No one up to this time had thought apparently of using insulated wire coiled in layers, and immediately after Henry described his apparatus all the investigators of Europe adopted the idea. Faraday, in his original apparatus, used when he made his discovery of electromagnetic induction, wound bare wire on an insulated iron ring, the separate coils being kept apart by winding between them a long twine, the separate layers being kept apart by pieces of non-conducting cloth. One can not tell by reading Faraday's papers whether this idea was original with him or whether it was adopted after having seen Henry's published paper. As a matter of fact, in no one of Faraday's papers is there any reference to the experimental work of Joseph Henry.

Henry's first application of this new principle of coiling long wires into a number of layers was in the construction of a small electromagnet which he exhibited before the Albany Academy in June, 1828; and, having found how successful it was, he made another more powerful one the following year, which he exhibited in March, 1829. He then had a new idea in regard to the winding of magnets and in the latter part of the same year made one in which he had two independent windings over the whole length of the iron core, so that he could join these two in parallel. Then, in order to make a magnet which could be used for many experimental purposes, in August, 1830, he wound one in a distinctly novel way, producing a magnet by far the most powerful then in existence. He wound the core of this magnet with nine separate coils, each coil occupying a space of about two inches. The terminals of each coil extended out from the side so that he was able to join the nine coils either in series or in parallel. This offered him a great variety of experimental possibilities. He investigated in connection with this magnet the effect of using a number of voltaic cells arranged in parallel or in series, and he emphasized the effect of having the cells when in series joined with the coils of his magnet also in series and similarly the effect of having either one cell or all the cells in parallel joined with the coils of his magnet when these were in parallel. He made a study of what we would to-day call Ohm's law so far as the effect of the internal resistance of batteries is concerned and also performed many other experiments, some of which I will refer to later. All this was in August, 1830. In November of the same year he saw in Brewster's *Edinborough Journal* an account of some work done by the Dutch physicist, Moll, in regard to electromagnets and thought it best to write an account of his work up to that time upon the same subject. This he did in November and submitted it for publication in *Silliman's Journal*. It was published in January, 1831, and was Henry's first scientific publication in a recognized scientific journal. It was characteristic of Henry for many years not to publish his results as soon as he had obtained them, but rather to wait until he had tested and investigated the various ideas which were in his mind on any one subject so that he would be convinced that he had exhausted the possibilities of that particular line of thought. This quality of his mind resulted naturally in the fact that so far as publication was concerned he was anticipated often, and he was in several cases persuaded by his friends to write brief accounts of what he had done after the publication by others of their work.

I refer above to experiments which Henry made with his final form of magnet, and these he did not include in his paper in *Silliman's Journal,* which was confined simply to a description of his magnets. His reason for not publishing some of these experiments, which were made in August, 1830, was because he intended to continue these further, and during August, 1831, he was very busy preparing some new apparatus, one portion of which was a large reel containing a mile of wire and another was a much more powerful electromagnet. In a letter of November 6, 1831, he says that he had been making this apparatus "for some contemplated experiments in the identity of electricity and magnetism." In another letter he says that he had to stop his work on this new apparatus because the room in which he was working was wanted for the classes of the academy. It is clear, therefore, that in August, 1831, he had been occupied with the construction of apparatus with the idea of continuing some of the work which he had begun in August, 1830, and which he had not thought to be sufficiently advanced to justify publication.

Immediately after the discovery of the fact that an electric current through a coil of wire would magnetize a piece of iron and in fact that a coil of wire carrying an electric current had magnetic properties, many investigators felt that there should be some way by which an electric current could be produced by means of a magnet, and experiments of various kinds were tried. Among others, Michael Faraday, of the Royal Institution, London, occupied himself with the problem for some years and on August 29, 1831, began a series of experiments which finally solved the problem. He reported the essential features of his experiments to the Royal Institution and also to the Royal Society, and preliminary accounts were published in the spring of 1832. Henry saw these, probably in June of that year, and thought it best to publish at once his preliminary investigations on the same subject, so that the first published account of his work appeared in the July, 1832, number of *Silliman's Journal.* In this account he describes experiments on the production of electric currents by varying the magnetic field through a coil of wire and also an observation which he had made some years before concerning the spark which is produced when an electric circuit is broken. He noted further that these two phenomena were evidently due to the same fundamental cause. I shall describe later the details of these experiments, but I wish at this time to call attention to the probable dates at which they were performed. In view of what I have said above I do not think there can be any doubt but that his observations of induced electric currents due to a varying magnetic field were carried out in August, 1830, when he was working with his new magnet. In fact, he says explicitly that the observations were made by using this magnet. When he observed the spark produced at the breaking of a circuit and studied the effect on this spark of various forms of the circuit, it is quite impossible to say. It certainly was an early observation, and the date has been set by Joseph Henry's daughter, Miss Mary Henry, as in 1829. This is extremely probable and the claim, I think, is supported by various considerations. Miss Henry says that she often talked with her father concerning the early history of electromagnetic induction and that he always spoke as if he had discovered induced currents in 1830 and made his first observations of self-induction in 1829. I think it is very reasonable to believe that it was his observation of the electric spark on breaking a circuit and certain other phenomena to which I shall refer later, these being made in August, 1829, that led him to undertake the experiments which culminated in the discovery of induced currents in August, 1830, after he had completed his new magnet. In any case he saw so much ahead of him in August, 1830, calling for the construction of new apparatus, that he thought it best not to publish his preliminary studies, so that August, 1831, found him busy making the apparatus which he felt necessary to have available to continue his investigations. Then, again, he was stopped in his work by the opening of the school session and probably he would not have published any full account of his studies until after August, 1832, if it had not been for the fact that he saw that Faraday had already made some of the discoveries with which he was familiar as the result of his own investigations.

After Henry saw the brief notes concerning Faraday's work he took up the problem anew, repeating some of Faraday's work and extending his own, although the latter was very complete and convincing.

Having made his powerful electromagnet, which I have described above (early in the summer of 1830), he wound a coil of wire around the armature of the magnet and led the terminals of the wires to an instrument for indicating current. He noticed that when he turned on the magnetizing current there was immediately a fling of the galvanoscope needle and that when he broke the magnetizing current there was a fling in the opposite direction. He further observed that when he turned the magnetizing current off and detached the armature there was also a fling of the galvanoscope needle, the amount of which varied according to the distance he moved the armature. Finally, he observed that when the armature was in place on the magnet and he varied the magnetizing current there was also a fling. So he felt justified in drawing the conclusion that there was an instantaneous current in one or the other direction in a helix of copper wire surrounding a piece of soft iron accompanying every change in the magnetic intensity of the iron. No statement concerning the production of induced electric currents could be any clearer than this.

His observation of certain phenomena of self-induction, probably made in 1829, was equally important. Having noticed this fact of the appearance of a spark which may have been and probably was a chance observation, owing to some break in an electric circuit, he studied the effect of having the circuit consist of a short wire or a long one and also the effect of coiling a conductor into a spiral or helix, noting the increased effect when the latter was done.

We have seen that in the summer of 1831 Henry was busy making a new magnet and new apparatus for experimental purposes. In 1832 he was elected professor of natural philosophy at the College of New Jersey, now Princeton, and he moved there with his family in November of that year. The first few years of his incumbency were occupied with the immediate duties of his chair and he did not have an opportunity to continue his studies until 1834. In November of that year Faraday published an account of his discovery of the phenomena of self-induction, and Henry's friends persuaded him that it was his duty to publish at once an account of what he had done on the same subject up to that time. This he did. He gave a verbal account of his work before the American Philosophical Society in Philadelphia at its meeting of January 16, 1835, and wrote a fuller account, which was published in *Silliman's Journal.* He had extended the observations to which I have referred above by investigating not alone the spark produced on breaking the circuit, but also the currents and the shock which accompanied the break. He had also studied the effect of introducing iron into a helix and had really made great progress. From this time on Henry worked fairly continuously and, apparently having learned his lesson in regard to publication, communicated his results as soon as he was convinced that they were definite. He had been elected a member of the American Philosophical Society in 1834 and hereafter he communicated his results to this society and they were published in its *Transactions* or *Proceedings*.

He continued for some years his study of the phenomena of self-induction and other effects of electromagnetic induction; in fact, there was a constant series of publications on the subject till his election as Secretary of the Smithsonian Institution in December, 1846.

In one series of experiments he investigated the effect of a discharge of a Leyden jar through his primary coil in producing induced currents in neighboring conductors and was ultimately led to the proof that such a discharge was oscillatory. (Conviction that this was the character of the discharge had been expressed previously in 1827, by Savaray, but this fact was not known by Henry.) He was able to prove also that this inductive action produced by discharges through a primary conductor was felt at considerable distances, certainly as far as two hundred feet. This is the first experiment on record of electromagnetic waves (in 1842).

One of his most important studies dealt with the effect of introducing sheets of conductors between his primary and secondary coils (in 1838). One of the main interests in this study lies in the fact that Henry's observations were quite contrary to those announced by Faraday. Henry showed that the introduction of a plate of copper cut off completely the inductive action, whereas Faraday had found that there was no shielding effect. The explanation of the discrepancy, which Henry, himself, was able to make, lies in the fact that Henry's observations were on what we nowadays call electromotive force, whereas Faraday in his investigations was concerned with the quantity of induced current. This fact emphasizes the difference in the experimental equipment of the two investigators. Henry had practically no measuring apparatus and had to content himself with such observations as sparks and the shocks received when discharges were passed through his body; Faraday, on the other hand, had a well-equipped laboratory. It is extremely interesting as one reads the papers by the two great physicists to see how they express themselves without having the benefit of the knowledge which came when Ohm's law was known. I think of the two men Henry had perhaps a clearer understanding of the essential features of induced currents, but I could not give conclusive proof of this. Both men were aware of the fact that there was one quality of the current which depended upon the rate at which the magnetic field is changed, this being what determines the shock in the muscles and the distance at which a spark will occur in a broken circuit, and that there was another property of the current depending upon the total change in the field, which determined the fling of the galvanometer needle. The former was independent of the material of the conductor, while the latter varied with it. It was not, however, until the work of Lenz and of Neumann that all the difficulties were removed and all the phenomena expressed in one simple equation.

One interesting experiment of Henry's in this connection was to show that although there were differences in the shock produced in the secondary coil when the current was made or broken in the primary, there was no difference at all in the fling of the galvanometer needle. This observation led him to a very careful study of the phenomena associated with making and breaking a circuit.

The discrepancies between the observations of Henry and of Faraday, depending upon the fact that the former was observing as a rule electromotive force, while the latter was measuring the quantity of current, reminds one very much of the discrepancies which existed in the early history of mechanics, discrepancies which were only cleared up by the mathematical work of D'Alembert. Mechanics had its origin, as is known to you all, in the work of Galileo, Newton and Huyghens, and in the century that followed their first publications a controversy arose as to the proper measure of those agencies in nature which produce the changes in velocity of a body. One school of writers insisted that the proper measure of the effect of such agencies was to be found in the difference in the squares of the velocities of the body at the beginning and the end of the action. Another school insisted vehemently that the effect should be measured by the difference in the velocity. If this dispute were stated in modern language it would be somewhat as follows: Is the effect to be measured by the change in the kinetic energy or by the change in the momentum? It was D'Alembert who first showed that neither one of them was the proper measure, because the change in the kinetic energy is equal to the product of the force by the distance through which the body moves under the action of the force, while the change in the momentum is equal to the product of the force by the time during which the body is under the action of the force. Or, it may be said, if one wishes to, that both schools were right and that they were looking at the two sides of the shield as in the ancient fable. Something of the same kind may be said in regard to the work of Henry and Faraday. Their research work was absolutely trustworthy, but their interpretation of this could not be completely satisfactory until the work of Ohm was appreciated and until the mathematicians had completed their study.

I can add but little to what is well known concerning Henry's qualities as an investigator and administrator. As one reads the various papers contributed to the memorial volume devoted to his life, one is struck by the universal admiration for his broad philosophy, his accuracy of observation, his brilliant intuitions and his devotion to the cause of science in its widest interpretation. He was unselfish to a marked degree. He was not interested the faintest in personal advancement or in advancing claims for discoveries or inventions. His sole purposes in life were to interpret nature and to diffuse knowledge among men. Beyond any doubt he is the outstanding figure in the history of the scientific life of America.

THE RELATIONSHIPS OF THE NATURAL SCIENCES AND THE SOCIAL SCIENCES IN AGRICULTURAL EDUCATION IN THE UNITED STATES[1]

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IN this country the program of agricultural education, as it relates to both teaching and research, centers in the natural and social sciences. It is perhaps safer and wiser to describe the functions of these sciences in this program in rather broad and general terms, as no two persons would likely fully agree on any exhaustive statement about either of them.

Natural science, in its application to agricultural and pastural products intended for consumption, has to do with improving and increasing production by reducing the amount of time or effort necessary to produce a unit of product and by making more resources for production available. It is addressed to the soil for such purposes as increasing balancing and maintaining its plant food elements, controlling its moisture content and improving its condition with respect to tillage. It is applied to plant life as it relates to agriculture and deals with the breeding and selection of plants and their adaptation to given conditions and needs. It has to do with their culture and with means of protecting them from the ravages of disease and insect pests. Along practically the same lines it deals with animal life in agriculture. And it also has to do with the interrelationships of soil and plants and animals.

Social science deals with human wants and primarily those which are satisfied only by associated or

[1] Address of the retiring vice-president and chairman of Section O—Agriculture, American Association for the Advancement of Science, New Orleans, December 29, 1931.