Joseph Henry

JOSEPH HENRY

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THE coming celebration of Faraday's discovery of the induced current has drawn attention to the work of an American physicist, which for some years ran curiously parallel to the work of Faraday. Joseph Henry was one of the pioneers in the field of the induced current. That his work has been so generally ignored may be ascribed to the circumstances of his life and to the modest, almost reluctant, way in which he brought forward his discoveries. It is fitting at this time, when everyone is interested in recalling the events of a great epoch in science, to present to the world some account of Henry's life and work.

Such an account has already been given and well given in the memorial address by William B. Taylor, published along with other memorial addresses in a volume issued by order of Congress in 1880. Almost all that is known or that now can be known about Henry is contained in that volume and in the two volumes of his scientific works published by the Smithsonian Institution. A few additional facts of importance are reported by his daughter, Miss Mary A. Henry, in papers in the Electrical Engineer and the Electrical World. From these sources and a few scattered traditions, this paper has been prepared, in the hope that it will lead to a renewed appreciation of Henry's place in the history of electricity, as well as to a recognition of his eminent qualities as a scientific man.

Life

Of Henry's family little is known. His grandparents on both father's and mother's side came from Scotland in the same ship and landed at New York the day before the battle of Bunker Hill. They apparently proceeded at once to Albany, New York, and settled there or in the neighborhood. His father, William Henry, was a day laborer, as appears from an entry in the baptismal register of the First Presbyterian Church of Albany, in connection with the record of the baptism of Henry's sister. His mother was named Ann Alexander. Henry was born in Albany on December 17, 1797. The date, which is often given as 1799, is fixed by an entry in the same baptismal register.

While Henry was still a little boy he was sent to live with his maternal grandmother in Galway, a village in Saratoga County, about forty miles from Albany. His father died a few years later, and it may be conjectured that this change of residence had to do with his father's health and the poverty of the family. He attended the district school in Galway, and from the age of ten years on he also worked part of the day in the general store of the village. He had shown no special ability in his studies, but his interest in literature was at that time excited in a peculiar way. One day his pet rabbit escaped from its hutch and ran under the village church. The boy followed it on his hands and knees, and in his progress he noticed a light coming through some loose boards in the floor above him. He crawled through the opening thus presented and found himself before the bookcase containing the village library. He took down one of the books, Brooks's "*Fool of Quality*," and was so fascinated by it that he read on until it was time to leave. He returned frequently to this new source of delights by the same passage, but was eventually detected by his master at the store, who, so far from finding fault with him, arranged for his admission to the library in the ordinary way. His reading was almost entirely in fiction, and he used to tell the stories that he had read to the audience that gathered every evening in the store.

When he was about thirteen years of age, Henry returned to Albany to live with his widowed mother. He was apprenticed to a watchmaker and jeweler and worked with him two years, but his master failed in business, and set him free. He did not like the work and said subsequently that "he was considered too dull to learn the trade." His heart was really set elsewhere. While still at Galway he had been taken on a visit to Albany and had there seen a play at the local theater. He was immensely excited and stimulated by it, and when he came to Albany to live, he not only attended the theater whenever he could, but set out to become a dramatic performer. He joined an association of young people, called the Rostrum, formed for the purpose of giving theatrical performances, and so distinguished himself by his skill in arranging stage effects and by his own acting that he was made president of the association, and for two or three years devoted most of his time and thought to the preparation and presentation of plays. He even wrote a play or two which were given by himself and his associates.

One day, when he was about sixteen years old, he was kept at home by some slight injury and to while away the time he picked up a book that had been left on the table and began to read. The book was a popular work on science entitled, Lectures on Experimental Philosophy, Astronomy and Chemistry, by G. Gregory, D.D., Vicar of West-ham. The questions with which it opened caught his attention: "You throw a stone, or shoot an arrow into the air; why does it not go forward in the line or direction that you give it? Why does it stop at a certain distance and then return to you? . . . On the contrary, why does flame or smoke always mount upward, though no force is used to send them in that direction? And why should not the flame of a candle drop toward the floor when you reverse it, or hold it downward, instead of turning up and ascending into the air? . . . Again, you look into a clear well of water and see your own face and figure, as if painted there. Why is this? You are told that it is done by the reflection of light. But what is reflection of light?" Such questions as these and the answers given to them revealed to him for the first time the delights of scientific investigation. He made his determination at once. At the next meeting of the Rostrum, he formally resigned his office as president, and announced his intention to devote himself from that time on to the pursuit of knowledge. The friend who owned the book which had had so marked an effect, was so much pleased with the boy's interest that he gave it to him. Henry always preserved it among his memorials, and on the fly-leaf he wrote, in 1837:

> This book, although by no means a profound work, has under Providence, exerted a remarkable influence on my life. It accidentally fell into my hands when I was about sixteen years old, and was the first book that I ever read with attention. It opened to me a new world of thought and enjoyment; invested things before almost unnoticed with the highest interest; fixed my mind on the study of nature, and caused me to resolve at the time of reading it that I would immediately commence to devote my life to the acquisition of knowledge. J. H.

Fired with this new interest, Henry set himself to get an education. He at first attended a night school in Albany, until he had acquired all that he could learn there. He studied grammar under an itinerant pedagogue, and succeeded so well that though only a boy he was able to put his acquirements to use by teaching the rudiments while on a wandering tour through the country districts. He was at last admitted to an advanced class in the Albany Academy. This institution was at that time one of the most distinguished in the country. It was not a college, in the sense that it did not confer degrees, but the instruction there given, though beginning low, was carried on in certain lines well into the collegiate grades. Henry's course was interrupted at least once by his need of money, which led him to seek and obtain employment as a teacher in a district school, in which he started at a salary of eight dollars a month, which was voluntarily raised by the trustees, after the first month's trial, to fifteen dollars. Later, while still a student, he was made an assistant in the Academy, and from that time on was able to pursue his studies without interruption. After he finished the course at the Academy he was for two years a tutor in the family of General Stephen Van Renssalaer. He used his leisure time, which was considerable, in chemical and physiological studies, with the view of entering the medical profession. He also continued his studies of mathematics. It is said that he progressed so far as to read *Lagrange's Mécanique Analytique.*

In 1826 an influential friend procured for Henry an appointment as an engineer to help carry out a survey of a road across the State of New York, from West Point on the Hudson to Lake Erie. His health had been showing the effect of his close confinement to his studies, so that this appointment gave him a welcome change of life. He worked hard and successfully on this expedition, which continued into the winter and traversed very rough and wild country. The work was so interesting to him that he was contemplating taking on the direction of the construction of a canal in Ohio, when he was unexpectedly asked to be a candidate for a post in the Albany Academy which had recently become vacant. He was elected in the spring of 1826 to the Professorship of Mathematics and Natural Philosophy, and entered upon his functions in September. Some of the intervening months were spent as an assistant to Professor Eaton, of the Renssalaer Polytechnic Institute, in a geological exploration of the neighboring counties.

Henry had already been received as a member of the Albany Institute, a society formed to promote scientific study and research, and had presented papers on the effects exhibited by steam escaping under high pressure, on the cooling produced by rapidly expanding air, and on flame. When he entered upon the work of his professorship he began to investigate the phenomena of the relations of electricity and magnetism, a subject then new and undeveloped. The conditions under which he worked could hardly have been more unfavorable. He taught for seven hours a day, spending much of this time in driving arithmetic into large classes of little boys. The only room in which he could set up the more elaborate of his experiments was the auditorium of the Academy, which was needed for other purposes when the school opened in September, so that most of his work was done in the summer and was laid aside for the academic year. His means were so small, and the difficulty of getting material so great, in what was then almost a frontier town, that his work was delayed and sometimes interrupted for the lack of so small a matter as a piece of zinc. It is plain from his papers that this situation determined the course of his earliest electrical investigations, which were carried out in the interests of economy. He frequently refers in them to the fact that results which had previously been obtained only by the use of powerful batteries, could be obtained by his arrangements with a small single cup. The most unfavorable feature of his situation was, however, his isolation from the centers of scientific activity and sources of information. As late as 1833, he asked his friend, Dr. Bache, to give him some information about the theory of Ohm. He heard of Faraday's discovery of the induced current in June 1832, from an announcement in the *Annals of Philosophy* for April of that year of a lecture by Faraday at the Royal Institution, though Faraday's results were presented to the Royal Society on November 24, 1831. The memoir in which they were described did not reach this country until a year later. One or two friends were associated with him in his early researches, but it is plain that they were little more than helpers in the very considerable manual labor which that work entailed. After he published his first paper in Silliman's Journal, he began to receive recognition and support from other American men of science, but it was not until his journey to England and France in 1837 that he formed the acquaintance of European investigators in his field of study.

Henry was connected with the Albany Academy from September 1826 to November 1832. In that period he developed and improved the electromagnet, constructed and operated an electromagnetic telegraph, made one of the first motors worked by electromagnets, discovered the extra current or current of self-induction, and independently discovered electromagnetic induction. His papers on these subjects were published in Silliman's *American Journal of Science*, and at once gave him a reputation in this country as an investigator. They seem to have had very little recognition abroad, though the improvements which he introduced in the construction of electromagnets were immediately adopted everywhere.

In May, 1830, Henry was married to Miss Harriet L. Alexander, of Schenectady, New York, a first cousin. There were born of this marriage two children who died in infancy, a son, William Alexander Henry, who died in 1862, and three daughters, Helen, Mary A., and Caroline, who with their mother survived him.

In 1832 the Chair of Natural Philosophy in the College of New Jersey at Princeton became vacant by the resignation of Professor Vethake, and Henry was called by the Trustees of the College to the post, at a salary of $1000 a year. He removed to Princeton in November of that year. He was at first so occupied with his new duties that he had little time for research, but he was able to develop his original observation on the current of self-induction, a subject which was also taken up by Faraday in 1834. He constructed a large magnet, and set up a local telegraph line between his house and his laboratory. In 1837 the Trustees gave him a year's leave of absence on full salary. He sailed for England in company with his friend, Professor Bache, on the Wellington, of 750 tons. In England he had many interviews with Faraday, and formed with him a cordial friendship. He also met Wheatstone and discussed with him the essentials of telegraphy. In Paris he met most of the prominent ment then living at that center of scientific activity. In September he attended the meeting of the British Association for the Advancement of Science and presented two papers.

After his return to his duties as professor he took up the investigation of the induction of one current by another, and studied higher orders of induction. He also investigated the induction currents produced by the discharge of a Leyden battery through a primary circuit, and showed that this action could be transmitted through space for several hundred feet. In this connection he showed that by proper arrangements what he called a "quantity" current would produce an "intensity" current, or an intensity current a quantity current, as in the step up and step down transformers. Henry's services to the College were recognized by the Trustees as far as they were able by an increase in salary to $1200 and then to $1500, with the use of a house which was built for him on what is now the site of Reunion Hall. This house after two removes still stands on the college campus. The increase in salary may have been more apparent than real. Professor Brackett used to say that Henry told him that he sometimes received in the year only $600. Still, his friends on the Faculty admired him, the students respected him, and he was able to carry on his investigations without serious pressure from other duties. He used to say that the years spent in Princeton were the happiest period of his life, and he always looked upon the college with affection. After he left it to become the Secretary of the Smithsonian Institution he was made a Trustee of the College, and when in 1853 the presidency became vacant, he was warmly urged by his brother trustees to become a candidate for that position. For many years after leaving the college he returned each year for two or three weeks to give a short course of lectures on some branch of natural philosophy.

The Act of Congress establishing the organization of the Smithsonian Institution was approved on August 10, 1846. The Board of Regents constituted under this act at once proceeded to elect a Secretary who should be in all essentials the Director of the Institution, and of whom it was remarked "that upon the choice of this single officer, more probably than on any other act of the Board, will depend the future good name and success and usefulness of the Smithsonian Institution." The Board adopted the following resolution:

RESOLVED, That it is essential for the advancement of the proper interests of the trust, that the Secretary of the Smithsonian Institution be a man possessing weight of character, and a high grade of talent; and that it is further desirable that he possess eminent scientific and general acquirements; that he be a man capable of advancing science and promoting letters by original research and effort, well qualified to act as a respected channel of communication between the Institution and scientific and literary individuals and societies in this and foreign countries; and, in a word, a man worthy to represent before the world of science and of letters the Institution over which this Board presides.

It was felt by the Board that Henry met the qualifications thus clearly stated, and he was accordingly elected as Secretary on December 3, 1846. His reluctance to accept the position was unfeigned. The use to be made of Smithson's bequest had been a subject of lively discussion in Congress for eight years, and the Act establishing the Institution by no means settled all the disputed questions. Henry's life at Princeton was very congenial and he was in the full tide of investigation. He realized that the new post would require great labor and might involve him in disagreeable controversy, while at the same time it would so fully occupy his time and thought as to make further advances in science impossible. As he put it, "If I go, I shall probably exchange permanent fame for transient reputation." It required all the pressure of his sense of duty to his country, which had accepted Smithson's bequest, backed by the solicitations of his friend Professor Bache, to force him to decide to exchange his free scientific career for that of an organizer and an administrator. He accepted the appointment and removed to Washington on December 14, 1846, to take up his new office.

His salary was at first fixed at $3500 a year, with an allowance of $500 for house rent, until such time as rooms could be provided for him in the building of the Institution. His salary was raised in 1865 to $4500, and a suite of seven rooms on the second floor of the Smithsonian Building was alloted to him and occupied by him as a residence for himself and his family until the end of his life.

In this office Henry labored for thirty-one years. The plan of organization which he presented to the Board of Regents in his first annual report was adopted by the Board on December 13, 1847. It proposed to carry out the intent of Smithson that the Institution founded by him should serve for "the increase and diffusion of knowledge among men" by assisting original research by furnishing means for publication of memoirs submitted to the Institution and by grants of money to investigators, and by distributing throughout the country and abroad reports on the progress of science. For several years the Institution was burdened with the necessity, under the Act of Congress, of accumulating a library and collections of objects of science and art. The Secretary endeavored to impress upon Congress the importance of relieving the Institution of these burdens on its income, and after years of controversy he had the pleasure of knowing that his efforts were successful, and that his original plan could be carried out without hindrance. From that time on, the Smithsonian Institution has been a most valuable agent for the increase and diffusion of scientific knowledge.

Henry's time and thought were so engaged in the work of his office that he could give little attention to his own researches. A fire which occurred in the Smithsonian building in January 1865 consumed all the notes of his many unpublished experiments, which had been either not reported at all or reported very imperfectly. The loss was one which in the circumstances he was never able to repair.

When the Light House Board was established in 1852, Henry was appointed one of its members. He served continuously until his death as Chairman of its Committee on Experiments, and after 1871, as Chairman of the Board. Most of his scientific work of this period was done in connection with this Committee. He made an elaborate research on the different oils that could be used in the lamps, and for many summers he spent his vacations at various light house and signal stations, investigating the behavior of fog signals of different sorts and the curious regions of inaudibility which are sometimes found at sea. In 1870 the Board of Regents proposed without Henry's knowledge that he should be granted leave of absence for several months to visit Europe in the interests of the Institution, and that $2000 be given him for expenses. He took advantage of this offer and sailed from New York on June 1st. He spent four and a half months abroad, and though his opportunities were somewhat curtailed by the Franco-Prussian War, he visited England, Scotland, Ireland, Belgium, and parts of Germany and France. He reported that he "was highly gratified with the commendations bestowed on the character and operations of the Institution."

Henry was one of the original members of the National Academy of Sciences at its organization in 1863; he became its Vice-President in 1866 and its President in 1868, and was continued in this office until his death. He helped to organize the American Association for the Advancement of Science in 1847 and was President of it at its second meeting in Cambridge in 1849. He assisted in organizing the Philosophical Society of Washington in 1871, and took an active part in its proceedings. He was a member of the American Philosophical Society and most of the papers which he published during his Princeton period appeared in its Proceedings.

In the summer of 1877, while he was engaged in his work at one of the signal stations, he noticed a partial paralysis of the right hand. The paralysis was only temporary, but was symptomatic of an affection of the kidneys which progressed with unexpected rapidity and led to his death at Washington on Monday, May 13, 1878, at 12:10 o'clock p.m. His death was felt as a public calamity. His funeral in the New York Avenue Presbyterian Church was attended by all who were prominent in official and public life, by representatives of the various interests with which he was connected and by hosts of private friends. By concurrent resolution of both Houses of Congress, Memorial exercises in honor of Joseph Henry were held in the Hall of the House of Representatives on Thursday evening, January 16, 1879. The Vice-President presided, and there were present the President of the United States, the members of his Cabinet, the Chief-Justice and the associate justices of the Supreme Court, the Regents of the Smithsonian Institution, and representatives of various scientific societies, besides the general public.

Never before or since in the history of our country has so great an honor been paid to a man who had no political or military eminence, and who was distinguished only by the services which he had rendered to science and by the weight and beauty of his character.

The Albany Period

Henry's first paper on the electric current was read before the Albany Institute on October 10, 1827. In it he describes improvements which he had made in the various pieces of apparatus designed to demonstrate the mutual actions of currents and the behavior of currents in magnetic fields. The improvement consisted in every case in the substitution for the single bare wire that had been generally used of a coil of wire, the separate turns of which were insulated from one another by wrappings of silk. In this way he succeeded in his object, which was "to form a set of instruments on a large scale which will illustrate all the facts belonging to this science with the least expense of galvanism." In this and in the subsequent papers on the electromagnet, the motive of economy is everywhere apparent.

In January 1831, Henry published in Silliman's *American Journal of Science* an account of his experiments on the electromagnet. Ten years previously it had been discovered by Arago that iron filings were attracted to a wire carrying a voltaic current, and by following out a suggestion of Ampère, Arago magnetized needles by placing them in the axis of a wire spiral carrying a current. Several years later a magnet was devised by Dr.Sturgeon which came into general use. To make this magnet a bar of soft iron in the ordinary horseshoe form was covered with sealing wax and a bare wire through which the current was sent was wound around it in a loose spiral. It occurred to Henry that "a much nearer approximation to the theory of Ampère could be attained by insulating the conducting-wire itself, instead of the rod to be magnetized; and by covering the whole surface of the iron by a series of coils in close contact." The first magnet made on that plan was exhibited to the Albany Institute in June 1828. A larger one was shown in the following March.

It was wound with thirty-five feet of wire covered with silk, so as to form about four hundred turns; a pair of small galvanic plates which could be dipped into a tumbler of diluted acid, was soldered to the ends of the wire and the whole mounted on a stand. With these small plates, the horseshoe became much more powerfully magnetic than another of the same size and wound in the usual manner, by the application of a battery composed of twenty-eight plates of copper and zinc each eight inches square.

It then occurred to Henry that the magnetic force might be still further increased, without changing the battery power or the length of wire used, by simply employing thicker bars of iron in the horseshoe. It was found on trial that this was the case. A further and important improvement was made about the same time. It consisted

.... in using several strands of wire, each covered with silk, instead of one: agreeably to this construction, a second wire, of the same length as the first, was wound over it, and the ends soldered to the zinc and copper in such a manner than the galvanic current might circulate in the same direction in both, or in other words, that the two wires might act as one; the effect by this addition was doubled, as the horseshoe, with the same plates before used now supported twenty-eight pounds.

With a pair of plates four inches by six inches, it lifted thirty-nine pounds, or more than fifty times it own weight.

These experiments conclusively proved that a great development of magnetism could be effected by a very small galvanic element, and also that the power of the coil was materially increased by multiplying the number of wires, without increasing the length of each.

Henry next proceeded, in collaboration with his friend, Dr. Philip Ten Eyck, to investigate the possibility of actuating a magnet when it formed a part of a long circuit. He used for the circuit 1060 feet of copper bell-wire stretched several times across the large room of the Academy. The current was supplied by a pair of plates each two inches square. The magnet was a small one made of a horse-shoe of soft iron, one-quarter inch in diameter, wound with about eight feet of copper wire. When this magnet was joined in circuit with the long wire, the magnetism of the horse-shoe was scarcely observable. A little more effect was produced when a larger battery was substituted. When half the length of wire was used the effect was greater. When the two halves of the wire were joined in parallel the effect was greater still. A considerably greater effect was produced by joining in the circuit a small Cruikshank's trough, containing twenty-five double plates. The same trough joined directly to the magnet without using the long wire gave even a less effect. Henry evidently doubts the validity of this result, but says about it that "the fact, that the magnetic action of a trough is, *at least*, not sensibly diminished by passing through a long wire, is directly applicable to Mr. Barlow's project of forming an electromagnet telegraph; and it is also of material consequence in the construction of the galvanic coil. From these experiments it is evident that in forming the coil we may either use one very long wire, or several shorter ones as the circumstances may require: in the first case, our galvanic combinations must consist of a number of plates so as to give 'projectile force'; in the second it must be formed of a single pair." The two forms of magnet thus described constitute respectively what Henry called "intensity" and "quantity" magnets.

A larger magnet was then made, designed particularly for experiments. (See Fig. 2) The bar bent into horse-shoe form was twenty inches long and two inches square. It was wound with nine coils of wire each sixty feet long, in short spools. The ends of these coils were left projecting and were all numbered, so that the first and the last end of each coil could be distinguished. By soldering these ends in different combinations many variations in the number of effective turns of wire could be obtained. With this magnet, when all the nine coils were joined in parallel and a small battery was used, in which was a plate of zinc twelve inches by six, surrounded by copper, a weight of 750 pounds was sustained. This was more than thirty-five times the weight of the magnet.

When two of the coils were brought into the circuit in series, it was observed that the lifting effect produced by a small single cell was almost doubled when two cells in series were used. These are said to have more "projectile force" and thus to produce a greater effect with a long wire.

Henry's publication of these results was hastened by the appearance in the *Edinburgh Journal of Science* of a paper by Professor Moll of Utrecht, in which he described some powerful electromagnets constructed by him. Moll's magnets were large and were used with powerful batteries. They were, however, wound with only a single layer of wire, and were really only enlarged or improved Sturgeon magnets. Judged by the ratio of the weight sustained to the weight of the magnet, they were not nearly so powerful as Henry's magnets. The difference between the two methods of construction was not always noticed. Thus we find Faraday in his paper on electromagnetic in-

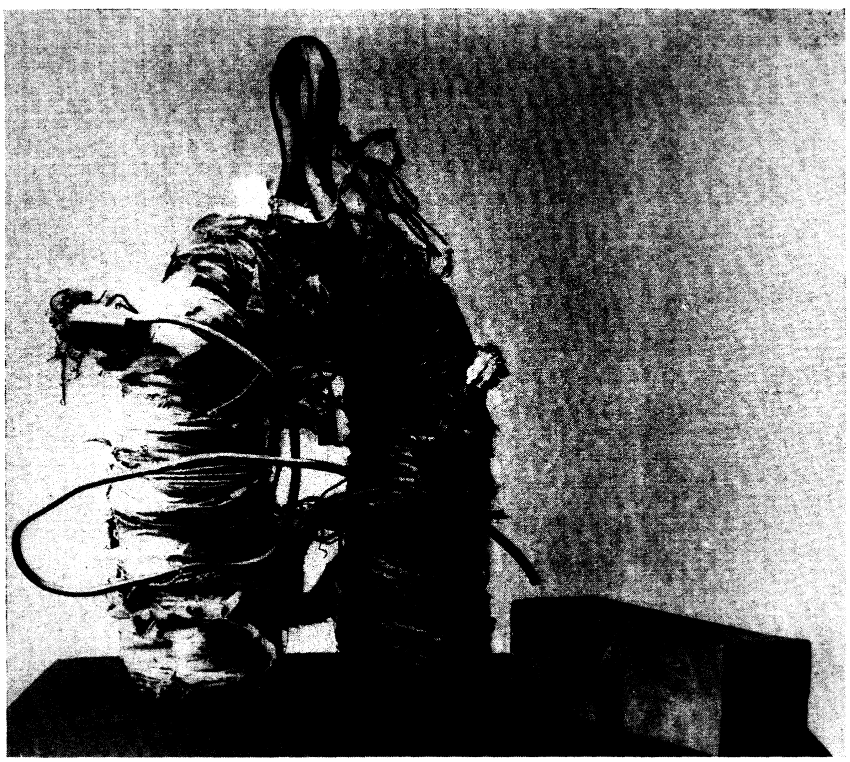

Fig. 2. One of Joseph Henry's electromagnets.

duction speaking of the magnets of Professors Moll, Henry, Ten Eyck and others as being essentially similar and equally useful.

In 1831 he made a large electromagnet for the laboratory of Yale College, which when excited by a single galvanic element presenting about five square feet of active surface, lifted 2300 pounds. A still larger one, which he made for the College of New Jersey after his removal to Princeton, could sustain a weight of 3600 pounds.

Henry at once applied his results to the invention of an electromagnetic telegraph. Using an intensity magnet, wound with many turns of wire, and a small galvanic trough, he was able to actuate the magnet through more than a mile of wire, strung around one of the rooms in the Academy. A small permanent magnet poised on a pivot was so placed that it swung against a bell and gave a signal, whenever the current was made. When Henry removed to Princeton he stretched a wire from his laboratory to his house, a distance of several hundred feet, completing the circuit through the earth by sinking the ends of the wire in two wells, This he believed was the first actual line of telegraph which used the earth as a conductor. The current in this circuit excited a small magnet which pulled toward it a short iron bar laid across the poles, and carried on one end of a wooden lever, on the other end of which was a hammer by which a bell was struck. (See Fig. 3) With an intensity magnet

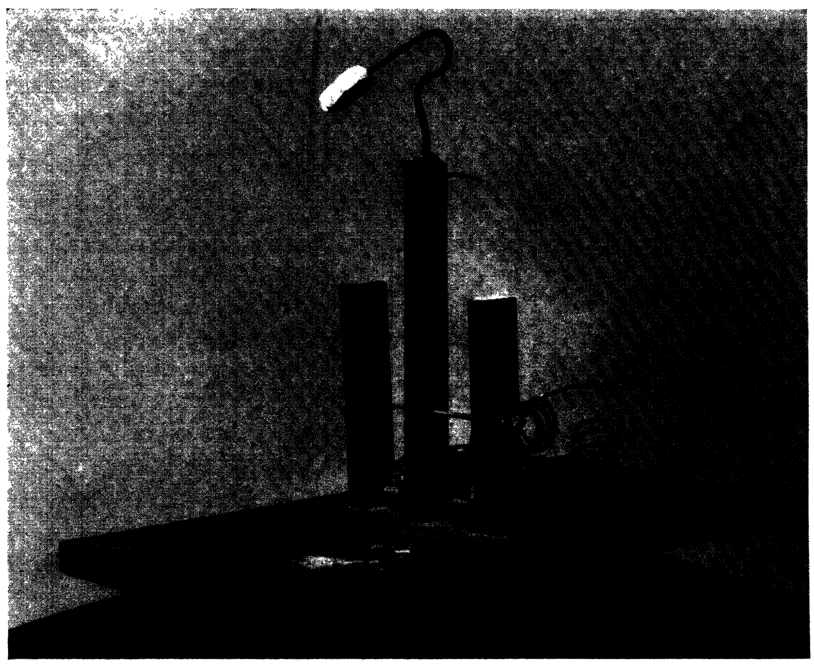

Fig. 3. Henry's electric bell.

in this same circuit he was able to move a forked wire dipping into two mercury cups so as to make or break the local circuit of his large magnet. This arrangement is essentially that used in the telegraph relay, which is necessary in telegraphing over long distances. These discoveries or inventions were made before Henry's trip to Europe in 1837. They were not published at that time, at least in a form in which their applicability to the solution of the problem of long distance telegraphy was clearly stated, but they were publicly exhibited to Henry's students and to scientific friends, and there is abundant evidence, not only from Henry's later statements but from the statements of others, for the dates which have been assigned to them.

Samuel F. B. Morse, the patentee of the first form of electromagnetic telegraph which was put to actual use in the transmission of messages, made the first model of his receiving instrument in 1835. He used a single cell and a Sturgeon magnet, and was disappointed to find that while the instrument worked on a short circuit it ceased to work when even forty feet of wire were inserted in the circuit. In 1837 a colleague of his, Dr. Gale, Professor of Chemistry in New York University, who was familiar with Henry's work, suggested that he use a battery of cells in series and a magnet wound with many turns of wire. When this arrangement was tried it was found that the instrument could be worked in a long circuit, and messages were sent through 1000 feet of wire. A caveat was filed by Morse on October 3, 1837, describing the details of the instrument which he then employed. On April 7 of the following year, he applied for a patent on the original instrument as described, and on a new and improved form of it, worked out by his partner, Albert Vail, and also on a system of alphabetical symbols and on a relay for introducing successive circuits. The patent was issued on June 20, 1840. After years of effort, Morse secured an appropriation by Congress for the erection of a telegraph line between Baltimore and Washington, and on May 24, 1844 the first message was transmitted over that line.

Apparently Morse forgot the obligations under which he lay to Henry's inventions, and perhaps his head was a little turned by the adulation which he was receiving, for in 1855 he published a pamphlet in which he undertook to show that he was "not indebted to Henry for any discovery in Science bearing on the telegraph, and that the claim set up for Henry to the invention of an important part of his telegraph system had no validity in fact." In answer to the first statement Henry appealed to the testimony of Professor Gale, who in reply described again the failure of Morse's original apparatus to work through a long circuit, and the success which was attained when at his suggestion Henry's intensity magnet and an intensity battery were introduced. The second statement seemed to Henry an imputation on his honor. He made no answer himself directly, but appealed to the Regents of the Smithsonian Institution and laid a full statement of the facts before a Committee of the Board. He summarized his contributions in the following words:

> From a careful investigation of the history of electromagnetism in its connection with the telegraph, the following facts may be established:
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> 1. Previous to my investigations the means of developing magnetism in soft iron were imperfectly understood, and the electromagnet which then existed was inapplicable to the transmission of power to a distance.
> 2. I was the first to prove by actual experiment that in order to develop magnetic power at a distance, a galvanic battery of intensity must be employed to project the current through the long conductor, and that a magnet surrounded by many turns of one long wire may be used to receive this current.
> 3. I was the first actually to magnetize a piece of iron at a distance, and to call attention to the fact of the applicability of my experiments to the telegraph.
> 4. I was the first actually to sound a bell at a distance by means of the electromagnet.
> 5. The principles I had developed were applied by Dr. Gale to render Morse's machine effective at a distance.
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> The results here given were among my earliest experiments; in a scientific point of view I consider them of much less importance than what I subsequently accomplished; and had I not been called upon to give my testimony in regard to them, I would have suffered them to remain without calling public attention to them, a part of the history of science to be judged of by scientific men who are the best qualified to pronounce upon their merits.

The Regents after an examination of all the available evidence declared that these results were "within what he might fairly have claimed," and expressed in the warmest terms their appreciation of Henry's integrity.

The first electromagnetic motor seems to have been invented by Salvatore dal Negro in 1830. In July of the following year, Henry published in Silliman's *Journal* an account of a somewhat similar machine, which he had independently invented. A bar electromagnet about nine inches long was balanced horizontally so that its ends stood over the poles of two permanent magnets fixed vertically. Two pairs of terminals were joined to the wire of the electromagnet and bent down so that when the electromagnet was tilted in one sense, one pair of terminals dipped into mercury cups joined to the copper and zinc of a galvanic cell. The current was thus sent through the wire in such a sense that the end of the electromagnet nearest the pole of one permanent magnet was of the same polarity. This end was repelled and lifted while the other end was attracted. The circuit was thus broken and, as the rocking bar moved on, the other pair of terminals was dipped into mercury cups joined to the copper and zinc of another cell. These terminals were so arranged that the current entering them passed through the wire in such a way as to reverse the magnetism in it and thus brought about a repulsion and an attraction as before, but in the opposite sense. The reciprocating motion thus set up continued for a long time when the batteries were properly adjusted. Henry considered the instrument in this form "a philosophical toy," but he ventured to say that "in the progress of discovery and invention, it is not impossible that the same principle, or some modification of it, on a more extended scale, may hereafter be applied to some useful purpose." In a letter written on December 4, 1876 to Rev. S. B. Dod, Henry says,

> I soon saw, however, that the application of this power was but an indirect method of employing the energy derived from the combination of coal, and, therefore, could never compete, on the score of expense, with that agent as a means of propelling machinery, but that it might be used in some cases in which expense of power was not a consideration to be weighed against the value of certain objects to be attained.

Henry was urged by a friend to take out patents on his types of electromagnet and on this motor, but this, he says:

> I declined, on the ground that I did not then consider it compatible with the dignity of science to confine the benefits which might be derived from it to the exclusive use of any individual. In this perhaps I was too fastidious.

On November 24, 1831 Faraday presented to the Royal Society the paper in which he describes his discovery of electromagnetic induction. Apparently, his first successful experiment was made on August 29th. This was followed by others from which nothing was learned, and it was not until September 24th that a convincing result was obtained. All the essential features of electromagnetic induction were presented in this paper.

Some time after his construction of his first large magnet, Henry's mind was occupied with the same problem as that which was solved by Faraday. Many men had felt that as magnetism, as they put it, could be developed from electricity, so it ought to be possible to develop electricity from magnetism. Many experiments looking toward the solution of this problem were tried, but no result had been achieved. Henry thought that with the greater magnetic force furnished by his magnets he might be able to succeed where others had failed. From a letter written to a friend, it is known that in August, 1831, he was engaged in constructing a large magnet and a reel containing a mile of wire for experiments on the relation between electricity and magnetism. What preliminary results he had obtained it is now impossible to tell, but it seems probable, when the available evidence is studied, that Henry did perceive the induced current at least in the summer of 1831, and possibly in the summer of 1830.

The opening of the school year at the beginning of September 1831 compelled Henry to lay aside his investigations for his professional duties. He expected to resume his work when the next summer came around. He was quickened into activity by learning that Faraday had obtained the desired evolution of electricity from magnetism. The story can best be told in his own words, taken from his paper of July, 1832 in Silliman's *Journal:*

Although the discoveries of Oersted, Arago, Faraday, and others, have placed the intimate connection of electricity and magnetism in a most striking point of view, and although the theory of Ampère has referred all the phenomena of both these departments of science to the same general laws, yet until lately one thing remained to be proved by experiment, in order more fully to establish their identity; namely, the possibility of producing electrical effects from magnetism. It is well known that surprising magnetic results can readily be obtained from electricity, and at first sight it might be supposed that electrical effects could with equal facility be produced from magnetism; but such has not been found to be the case, for although the experiment has often been attempted, it has nearly as often failed.

It early occurred to me, that if galvanic magnets on my plan were substituted for ordinary magnets, in researches of this kind, more success might be expected. Besides their great power, these magnets possess other properties, which render them important instruments in the hands of the experimenter; their polarity can be instantaneously reversed, and their magnetism suddenly destroyed or called into full action, according as the occasion may require. With this view, I commenced, last August, the construction of a much larger galvanic magnet than, to my knowledge, had before been attempted, and also made preparations for a series of experiments with it on a large scale, in reference to the production of electricity from magnetism. I was however at that time accidentally interrupted in the prosecution of these experiments, and have not been able since to resume them, until within the last few weeks, and then on a much smaller scale than was at first intended. In the mean time, it has been announced in the 117th number of the *Library of Useful Knowledge*, that the result so much sought after has at length been found by Mr. Faraday of the Royal Institution. It states that he has established the general fact, that when a piece of metal is moved in any direction, in front of a magnetic pole, electrical currents are developed in the metal, which pass in a direction at right angles to its own motion, and also that the application of this principle affords a complete and satisfactory explanation of the phenomena of magnetic rotation. No detail is given of the experiments, and it is somewhat surprising that results so interesting, and which certainly form a new era in the history of electricity and magnetism, should not have been more fully described before this time in some of the English publications; the only mention I have found of them is the following short account from the *Annals of Philosophy* for April, under the head of Proceedings of the Royal Institution:

"Feb. 17.—Mr. Faraday gave an account of the first two parts of his researches in electricity; namely, Voltaelectric induction and magnetoelectric induction. If two wires, A and B, be placed side by side, but not in contact, and a Voltaic current be passed through A, there is instantly a cur-

rent produced by induction in B, in the opposite direction. Although the principal current in A be continued, still the secondary current in B is not found to accompany it, for it ceases after the first moment, but when the principal current is stopped then there is a second current produced in B, in the opposite direction to that of the first produced by the inductive action, or in the same direction as that of the principal current.

"If a wire, connected at both extremities with a galvanometer, be coiled in the form of a helix around a magnet, no current of electricity takes place in it. This is an experiment which has been made by various persons hundreds of times, in the hope of evolving electricity from magnetism, and as in other cases in which the wishes of the experimenter and the facts are opposed to each other, has given rise to very conflicting conclusions. But if the magnet be withdrawn from or introduced into such a helix, a current of electricity is produced, whilst the magnet is in motion, and is rendered evident by the deflection of the galvanometer. If a single wire be passed by a magnetic pole, a current of electricity is induced through it which can be rendered sensible."

Before having any knowledge of the method given in the above account, I had succeeded in producing electrical effects in the following manner, which differs from that employed by Mr. Faraday, and which appears to me to develop some new and interesting facts. A piece of copper wire, about thirty feet long and covered with elastic varnish, was closely coiled around the middle of the soft iron armature of the galvanic magnet, described in volume XIX of the *American Journal of Science*, and which when excited, will readily sustain between six hundred and seven hundred pounds. The wire was wound upon itself so as to occupy only about one inch of the length of the armature which is seven inches in all. The armature, thus furnished with the wire, was placed in its proper position across the ends of the galvanic magnet, and there fastened so that no motion could take place. The two projecting ends of the helix were dipped into two cups of mercury, and there connected with a distant galvanometer by means of two copper wires, each about forty feet long. This arrangement being completed, I stationed myself near the galvanometer and directed an assistant at a given word to immerse suddenly, in a vessel of dilute acid, the galvanic battery attached to the magnet. At the instant of immersion, the north end of the needle was deflected 30° to the west, indicating a current of electricity from the helix surrounding the armature. The effect, however, appeared only as a single impulse, for the needle, after a few oscillations, resumed its former undisturbed position in the magnetic meridian, although the galvanic action of the battery, and consequently the magnetic power was still continued. I was however much surprised to see the needle suddenly deflected from a state of rest to about 20° to the east, or in a contrary direction when the battery was withdrawn from the acid, and again deflected to the west when it was re-immersed. This operation was repeated many times in succession, and uniformly with the same result, the armature the whole time remaining immovably attached to the poles of the magnet, no motion being required to produce the effect, as it appeared to take place only in consequence of the instantaneous development of the magnetic action in one, and the sudden cessation of it in the other.

This experiment illustrates most strikingly the reciprocal action of the two principles of electricity and magnetism, if indeed it does not establish their absolute identity. In the first place, magnetism is developed in the soft iron of the galvanic magnet by the action of the currents of electricity from the battery, and secondly the armature, rendered magnetic by contact with the poles of the magnet, induces in its turn currents of electricity in the helix which surrounds it; we have thus as it were electricity converted into magnetism and this magnetism again into electricity.

Another fact was observed which is somewhat interesting inasmuch as it serves in some respects to generalize the phenomena. After the battery had been withdrawn from the acid, and the needle of the galvanometer suffered to come to a state of rest after the resulting deflection, it was again deflected in the same direction by partially detaching the armature from the poles of the magnet to which it continued to adhere from the action of the residual magnetism, and in this way, a series of deflections, all in the same direction, was produced by merely slipping off the armature by degrees until the contact was entirely broken. The following extract from the register of the experiments exhibits the relative deflections observed in one experiment of this kind.

At the instant of immersion of the battery, deflection 40° west.
At the instant of emersion of the battery, deflection 18° east.
Armature partially detached, deflection 7° east.
Armature entirely detached, deflection 12° east.

The effect was reversed in another experiment, in which the needle was turned to the west in a series of deflections by dipping the battery but a small distance into the acid at first and afterwards immersing it by degrees.

From the foregoing facts, it appears that a current of electricity is produced, for an instant, in a helix of copper wire surrounding a piece of soft iron whenever magnetism is induced in the iron; and a current in an opposite direction when the magnetic action ceases; also that an instantaneous current in one or the other direction accompanies every change in the magnetic intensity of the iron.

It is clear from what Henry quotes in presenting the information which he had about Faraday's work, that he felt that emphasis was laid upon the motions of the magnets when the induced currents were produced, and that he thought that his experiment, in which no magnets were moved, was distinctly different from the other. After describing the experiment made before he had any knowledge of Faraday's method, he proceeds to describe others, in which, with a knowledge of Faraday's method, he investigates the production of currents by a combination of magnetism and motion. These results are of no special interest.

Henry never questioned Faraday's priority. He accepted without reserve the rule that priority of publication gives the right to a discovery. In his lectures on the subject, he always assigned the discovery to Faraday. It is, however, quite possible that it was really made by him.

Miss Mary A. Henry, his daughter, relates that often in the privacy of his family Henry expressed his regret that he had been so dilatory in publication. She says that the discovery of magnetoelectricity was made in 1830; that he was eager to pursue it but was baffled by lack of time and material. He desired to amplify his results before publishing them, and for that purpose undertook in the summer of 1831 the construction of a larger magnet. In June 1832 he got the news that he had been anticipated by Faraday in the publication of the discovery. Miss Henry quotes from Rev. Theodore L. Cuyler the following statement:

Your father often spoke to me of his disappointment about that discovery. "I ought to have published earlier," he used to say. "I ought to have published, but I had so little time. It was so hard to get things done. I desired to get out my results in good form and how could I know that another on the other side of the Atlantic was busy with the same thing."

Such statements as these indicate that the experiment which Henry says he completed before having a knowledge of Faraday's method was tried before June 1832. The magnet which he used in the experiment was his experimental magnet of 1830. Since he was engaged in the preceding summer in the construction of a larger magnet, which he says was made for the express purpose of pursuing the investigation of the production of electricity from magnetism, it seems probable that he had made preliminary observations with his smaller magnet before that time. The experiment as detailed in the paper already quoted may have been a repetition of earlier experiments made after he became aware of Faraday's work. Why, if he had obtained so important a result, he did not drop everything else and carry on his work to completion, and why, if he could not continue his work, he did not publish a preliminary notice, will never be known. He seems always to have been careless about publication. His paper on his magnets was delayed until he was stimulated to publication by finding out what Moll had done on the same matter. His discovery of the extra current was described in 1832, but the presentation of his extensive work on the subject was delayed until 1835. His isolation from all sources of scientific information may account for a good deal of his hesitation to publish.

In the same paper in which he describes his experiments on electromagnetic induction, he published the following paragraph:

ELECTRICAL SELF-INDUCTION IN A LONG HELICAL WIRE

I have made several other experiments in relation to the same subject, but which more important duties will not permit me to verify in time for this paper. I may, however, mention one fact which I have not seen noticed in any work, and which appears to me to belong to the same class of phenomena as those before described; it is this: when a small battery is moderately excited by diluted acid, and its poles which should be terminated by cups of mercury, are connected by a copper wire not more than a foot in length, no spark is perceived when the connection is either formed or broken; but if a wire thirty or forty feet long be used instead of the short wire, though no spark will be perceptible when the connection is made, yet when it is broken by drawing one end of the wire from its cup of mercury, a vivid spark is produced. If the action of the battery be very intense, a spark will be given by the short wire; in this case it is only necessary to wait a few minutes until the action partially subsides, and until no more sparks are given from the short wire; if the long wire be now substituted a spark will again be obtained. The effect appears somewhat increased by coiling the wire into a helix; it seems also to depend in some measure on the length and thickness of the wire. I can account for these phenomena only by supposing the long wire to become charged with electricity, which by its re-action on itself projects a spark when the connection is broken.

The phenomenon herein described was studied by Faraday without knowledge of Henry's work and published by him in 1834. This publication led to Henry's taking up the subject again in a paper presented to the American Philosophical Society on February 6th, 1835. The long interval between the original discovery and its subsequent amplification was a consequence of Henry's removal to Princeton in 1832, and the resulting calls upon his time and thought for the development of his courses of instruction.

The Princeton Period

The essential facts in regard to the extra current were presented by Henry to the American Philosophical Society on January 16, 1835. Some of his friends insisted on immediate publication, in order, as they said, in reference to Faraday's observations in the same field, "that the prior claims of our fellow countryman may not be over looked." The abstract which follows appeared in the *Journal of the Franklin Institute* for March:

The following facts in reference to the spark, shock, etc., from a galvanic battery of a single pair when the poles are united by a long conductor, were communicated by Professor Joseph Henry, and those relating to the spark were illustrated experimentally:

1. A long wire gives a more intense spark than a short one. There is, however, with a given surface of zinc, a length beyond which the effect is not increased; a wire of one hundred and twenty feet gave about the same intensity of spark as one of two hundred and forty feet.

2. A thick wire gives a larger spark than a smaller one of the same length.

3. A wire coiled into a helix gives a more vivid spark than the same wire when uncoiled.

4. A ribbon of copper, coiled into a flat spiral, gives a more intense spark than any other arrangement yet tried.

5. The effect is increased, by using a longer and wider ribbon, to an extent not yet determined. The greatest effect has been produced by a coil ninety-six feet long and weighing 15 lbs; a larger conductor has not been received.

6. A ribbon of copper, first doubled into two strands and then coiled into a flat spiral, gives no spark, or a very feeble one.

. . . .

. . . .

11. The property of producing an intense spark is induced, on a short wire, by introducing at any point of a compound galvanic current a large flat spiral, and joining the poles by the short wire.

. . . .

14. The effect produced by an electromagnet, in giving the shock, is due principally to the coiling of the long wire which surrounds the soft iron.

In the paper on this subject, which was published later, Henry says:

> The phenomena described in this paper appeared to be intimately connected with those of Magnetoelectricity, and this opinion I advanced with the announcement of the first fact of these researches in the *American Journal of Science*. They may, I conceive, be all referred to that species of dynamical *Induction* discovered by Mr. Faraday, which produces the following phenomenon, namely: when two wires A and B, are placed side by side, but not in contact, and a voltaic current is passed through A, there is a current produced in B but in an opposite direction. The current in B exists only for an instant, although the current in A may be indefinitely continued, but if the current in A be stopped, there is produced in B a second current, in an opposite direction, however, to the first current.

After his return from Europe in 1837, Henry took up the study of the induced current from a peculiar point of view. In a paper which was read to the American Philosophical Society on November 2, 1838, he says:

> The secondary currents, as it is well known, were discovered in the introduction of magnetism and electricity, by Dr. Faraday, in 1831. But he was at that time urged to the exploration of new, and apparently richer veins of science, and left this branch to be traced by others. Since then, however, attention has been almost exclusively directed to one part of the subject, namely, the induction from magnetism, and the perfection of the magneto-electrical machine: and I know of no attempts, except my own, to review and extend the purely electrical part of Dr. Faraday's admirable discovery.

From this quotation it may be conjectured that Henry did not appreciate that the production of the secondary current by the movement of magnets and by setting up or breaking a primary current were simply variants of the same action. His investigations were very elaborate and lasted over several years. They were presented in a series of contributions to the American Philosophical Society. It is impossible to do more than give an outline of the methods which Henry employed and to mention particularly some of his most important results.

For use in his investigations he prepared a number of flat coils of copper ribbon. These coils are shown in Fig. 4. The copper strip was about an inch and a half wide, and was insulated with two coatings of silk. Most of the coils contained about sixty feet of the ribbon, though some of them were longer. He also prepared a number of helices of insulated copper wire; the wires in these coils were of various lengths, the longest over 1600 yards. With two smaller ones of the same wire, so adjusted in size as to fit into each other, he could form one long helix of 3000 yards. He also obtained the loan of a still larger coil containing five miles of wire.

Fig. 4. Coils used by Henry in his experiments on electromagnetic induction.

To determine the direction of the current, he used a magnetizing spiral, consisting of a small number of turns of copper wire wound around a straw or a thin glass tube, in which a sewing needle could be inserted.

He also provided himself with a small horseshoe magnet wound with only a few turns of wire, so as to constitute one of his quantity magnets.

In his earlier experiments he used an ordinary zinc-copper battery in a single cell in which about one and three-quarters feet of zinc were exposed. Later, he substituted a set of Daniell's cells, which gave him a steadier primary current and by the use of which he was enabled to correct some of the impressions received from his earlier observations.

The first set of observations presented in the paper of 1838 relate to the properties of the extra current. By using the very long wires of his helices he showed that the current produced when the circuit was broken was of great intensity. In one instance, with the coil containing five miles of wire, with a battery formed of six pieces of copper bell-wire about one inch and a half long, and an equal number of pieces of zinc of the same size, the current when the circuit was broken gave a shock at once to 26 persons joining hands.

Proceeding to the consideration of the secondary current he observed that when the inductive action took place between one of his copper coils, used as the primary, and another similar coil, used as the secondary, the needle in the magnetizing spiral was strongly magnetized. Magnetism was exhibited by the small magnet and when the ends of the secondary were attached to a small decomposing apparatus, gas was generated at each pole. The shock from this coil was, however, very feeble. The induced current produced in this case had considerable quantity but low intensity. By using a longer coil as the secondary the indications of quantity did not increase, and in some cases diminished, but the shock was more pronounced.

A helix was then employed as the secondary. The decomposition produced by the current was much less than with the coil,

> . . . . but the shock was almost too intense to be received with impunity, except through the fingers of one hand. A circuit of fifty-six of the students of the senior class, received it at once from a single rupture of the battery current, as if from the discharge of a Leyden jar weakly charged. The secondary current in this case was one of small quantity but of great intensity.

Other variants of these experiments were tried without leading to any results of importance. When, however, a helix was made the primary and one of the copper coils served as secondary, there was obtained an induced current which gave no shocks but which magnetized the small horse-shoe. The current obtained therefore was one of quantity and it was produced by the inductive action of a current in the long helix from an intensity battery. This experiment was altered in many ways but always yielded the same result. Henry concluded that an intensity current can induce one of quantity, and that also a quantity current can induce one of intensity.

Experiments were next made on the possibility of obtaining inductive action in the secondary helix when it was removed from the plane of the primary coil. Apparently the test of the action was the shock felt in the fingers or the tongue, though in many cases the magnetizing spiral was used. Henry points out that this action at a distance affords a simple means of graduating the intensity of the shock when it is used for medical purposes.

Considerable attention was paid to the screening effect found when a sheet of conducting substance, such as a metal, was interposed between the primary and secondary. It was shown that the screening effect depended in some way on the induced current set up in the conductor, by cutting a triangular slice out of the plate and showing that with that plate the screening effect did not occur. The shock, when it was used, was as intense as if the screen were not present. By joining to the opposite edges of the cut the ends of a wire containing the magnetizing spiral, it was shown that a current existed in the conductor of the sort which had been supposed.

The next step in the series of investigations was the examination of induced currents of higher orders than the first. By joining the ends of the secondary coil to another coil at some distance from it and by using this last as the primary to induce a current in a secondary placed above it, a so-called tertiary current was obtained. By similar but more extensive arrangements, currents of higher orders up to the fifth were obtained. It was by no means evident before hand that any effects would be obtained from this arrangement. It was very natural to think that the sudden rise and fall of the current produced in the secondary might have effects in the tertiary which were so exactly opposite and which succeeded each other so rapidly that they would not give rise to any perceptible effect. It was found, however, that the effect as measured by the shocks perceived was very powerful, and that the magnetizing spiral also indicated the presence of a current. It was found in these cases also that quantity currents could be induced by intensity currents and conversely. A very careful study was made of the apparent directions of these currents of different orders. Henry devoted a great deal of time and trouble to this investigation, and in a later paper on the subject presented a theory of the action which it is not necessary to attempt to state.

The next set of experiments relates to the production of induced currents of different orders by ordinary electricity, that is, by the discharge of a charged conductor. Henry gives his reason for trying the experiment and describes his arrangements for it in the following paragraphs:

> The discovery of the fact that the secondary current, which exists but for a moment, could induce another current of considerable energy, gave some indication that similar effects might be produced by a discharge of ordinary electricity, provided a sufficiently perfect insulation could be obtained.
>
> To test this a hollow glass cylinder, (Fig. 5), of about six inches in diameter, was prepared with a narrow ribbon of tinfoil, about thirty feet long, pasted spirally around the outside, and a similar ribbon of the same length, pasted on the inside; so that the corresponding spires of the two were directly opposite each other. The ends of the inner spiral passed out of the cylinder through a glass tube, to prevent all direct communication between the two. When the ends of the inner ribbon were joined to the magnetizing spiral, containing a needle, and a discharge from a half gallon jar sent through the outer ribbon, the needle was strongly magnetized in such a manner as to indicate *an induced current through the inner ribbon in the same direction as that of the current of the jar*. This experiment was repeated many times, and always with the same result.

After detailing a number of experiments of a similar sort, Henry concludes that "from these experiments it appears evident that the discharge from the Leyden jar possesses the property of inducing a secondary current precisely the same as the galvanic apparatus."

By employing another cylinder similarly arranged with strips of tinfoil, of which one spiral was joined to the secondary of the first cylinder, a tertiary current was produced, which was detected by the magnetizing spiral. In a similar way a current of the fourth order was developed. Puzzling anomalies were discovered in the direction of these currents as compared with those which had been found in the former set of observations with the galvanic current. In particular the direction of the current seemed to change when the distance between the primary and secondary was altered. These anomalies were not understood until a year or two later, when it was found that they could be accounted for by the behavior of the magnet of the magnetizing spiral in the oscillating field set up by the discharge.

His next paper was read to the American Philosophical Society on June 19, 1840. It describes the induction produced at the making of the primary circuit. The experiments were tried with the Daniell's battery and certain

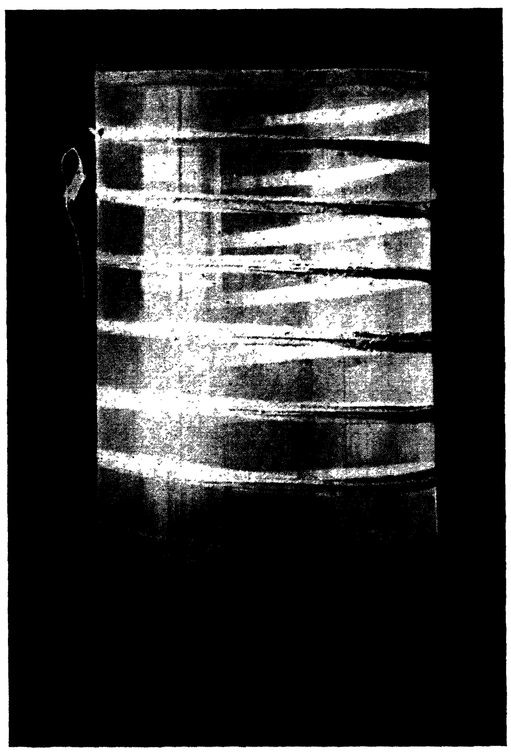

Fig. 5. Coil used by Henry to show the inductive action of the current produced by to an electrical discharge.

effects which were considered important in the earlier investigations were found to result from the inadequacy of the batteries formerly used. As an addendum to this paper, Henry presented in November his theoretical explanation of the currents of higher orders, which has already been referred to.

The last paper on this general subject was not printed in full, but from the proceedings of the American Philosophical Society of June 17, 1842, it appears that Henry presented a study of the peculiar anomalies exhibited in the directions of the currents of higher orders and that he succeeded in tracing them to the oscillatory character of these currents. Savary had discovered in

1826 that when needles were magnetized by discharging a Leyden battery through a spiral, the polarity of the needles in the spiral was not always in the same sense. Henry made many attempts to observe this peculiar result without success, but at last by the use of fine needles he succeeded in obtaining changes in polarity simply by increasing the quantity of the electricity while the direction of the discharge remained the same. The explanation of this peculiar result was given by Henry as follows:

> The discharge, whatever may be its nature, is not correctly represented (employing for simplicity the theory of Franklin) by the single transfer of an imponderable fluid from one side of the jar to the other; the phenomena require us to admit *the existence of a principal discharge in one direction, and then several reflex actions backward and forward, each more feeble than the preceding, until the equilibrium is obtained.* All the facts are shown to be in accordance with this hypothesis.

In the light of this explanation the apparent changes in direction of the induced current, produced by changes of distance, were examined and it was shown that they arise from the fact that the discharge from a jar produces a succession of currents in opposite directions. The effect on the needle is determined by the last one of the oscillations which is sufficiently powerful to reverse the polarity of the needle.

The magnetizing spiral proved itself extremely sensitive as a recorder of the induced current. By a single spark an inch long from his machine, thrown on a circuit of wire in an upper room, needles were magnetized in a secondary circuit in the cellar beneath at a distance from the primary circuit of thirty feet and with two floors and ceilings intervening. In a later experiment of the same sort, in which the spark was thrown upon the long telegraph wire stretched from the laboratory to Henry's house, and the receiving circuit was another long wire placed parallel with the first and over 250 feet away from it with the bulk of Nassau Hall intervening, it was found that the magnetizing spiral showed a current in the secondary. This occurred even when there was a break in the secondary, so that the action in it could not be ascribed to any possible leakage through the earth from the primary.

In a paper presented to the American Association in August 1851, Henry says in reference to the oscillatory discharge and to the great distances through which its inductive action can be transmitted that "As these are the results of currents in alternate directions, they must produce in surrounding space a series of *plus* and *minus* motions, analogous to—if not identical with undulations."

Henry's activity was not confined to the field of electromagnetism, though in none of the other subjects which he took up were his researches so systematic and extensive.

By a casual observation in which mercury seemed to pass by a sort of capillary action through the wall of a lead pipe he was led to the following experiment: A rod of lead about a quarter of an inch in diameter and seven inches long was bent into the form of a siphon and the shorter leg immersed in mercury. After twenty-four hours a globule of mercury was seen at the lower end, and in a few days all the mercury passed over, except a little which was retained in an amalgam in the upper vessel. This observation led him to other experiments in which he was able to demonstrate that under certain circumstances one metal, like silver, could penetrate another, like copper. By this observation some curious effects which had been observed in the metal trades were explained.

Henry made a careful study of phosphorescence, starting with the facts which were already known and proceeding to a search for other phosphorescent substances. He was led to believe from these experiments: "that the exciting cause of the phosphorescence is an emanation possessing the mechanical properties of light and yet so different in other respects as to prove the want of identity." That the emanation also differed from heat he considered proved by the fact that phosphorescence was excited when the emanation was sent through a plate of alum as well as through a plate of rock salt. Henry remarked, however, "that in considering these emanations as distinct, he had reference only to the classification of the phenomena, for if they be viewed in accordance with the undulatory hypothesis they may all be considered as the results of waves, differing in length and amplitude, and possibly also slightly differing in the direction of vibration."

Henry proposed a method for determining the velocity of projectiles. This consisted in an arrangement of two screens through which the projectile passed, so as to break circuits in which recording instruments were inserted. The records were made by marks on a revolving cylinder, the rate of revolution of which was known. He also proposed another method for making the record, in which the circuits broken by the projectile should be such as to give rise to a spark. The records were made by the sparks piercing the paper carried on the revolving cylinder.

A number of experiments were made on the cohesion of liquids, though nothing new of importance was discovered. Experiments were also made with the thermopile in collaboration with Professor Stephen Alexander on the heat radiating from different parts from the sun's disk, by which it was discovered that the radiation from sun-spots was less than that from the luminous surface of the sun.

The Washington Period

James Smithson, the founder of the Smithsonian Institution, was born in 1765. His mother was a widow named Macie. He believed himself to be the natural son of Hugh, the first Duke of Northumberland, and after he left Oxford, in which he had been entered under his mother's name, he assumed the family name of that Duke. At Oxford he had begun the study of chemistry, and within a year after leaving the university, he was admitted as a Fellow to the Royal Society on the recommendation of Cavendish, with whom he always maintained intimate relations. He devoted his life to the study of chemistry, and was the author of several papers published in the *Transactions of the Royal Society*, or in the scientific periodicals of the day. The later years of his life were clouded by ill-health. After his death, which occurred in 1829, in Italy, it was found that he had left by will his large estate, which apparently had been received from his mother, to his nephew; and that in the event of the death of this nephew without children, the property was to go "To the United States of America to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men."

In December, 1835, President Jackson notified Congress that the bequest to the United States became operative. After some delay, occasioned by a doubt as to whether or not the Government was constitutionally at liberty to accept such a bequest, an Act was passed authorizing its reception, and a friendly suit in Chancery was instituted, the result of which was that two years later the Government received under the bequest about £100,000. At that time this was a very considerable sum; it was larger than the endowment of any of the American colleges except Harvard.

The question of the proper disposal of the bequest was agitated in Congress for eight years. All sorts of projects were suggested. The proposal to found an astronomical observatory was supported by no less a man than John Quincy Adams, while Rufus Choate maintained the claims of a great library. Others proposed to establish courses of lectures to be given in Washington and in other cities of the country. A normal school, an agricultural college, a female institute, and other ways of disposing of the money were also urged. In the course of the discussion, the opinions of many leading men in science and literature had been obtained, among them one from Henry. At last in 1846 Congress, apparently finding itself unable to decide among the various plans presented, passed an act creating what was called the Establishment, consisting of the President of the United States, the Vice President, the Chief Justice, and the members of the Cabinet, and a Board of Regents to which the administration of the fund was entrusted. This Board was to consist of the Vice President, the Chief Justice, three members of the Senate, three of the House of Representatives, and six citizens elected by Congress. It was required in the act that the Regents should establish a Library and a Museum to contain collections in science and the arts. The Regents were further instructed to use whatever remained from the fund in the way best calculated to carry out the wishes of the founder. They were directed also to elect a Secretary, who was to serve under the Board as the executive officer of the Institution.

It was evident that in the working out of this plan everything depended on the man who was elected Secretary. It is not quite clear that the majority of the Board at the outset favored the disposition of the fund which had been suggested by Henry, but his proposals had attracted particular attention and his scientific eminence, as well as his known integrity and weight of character, indicated him as the most suitable person for the position of Secretary. He was elected to that position in December 1846, and he took up his duties as soon as he could remove from Princeton to Washington.

Henry's views for the proper disposition of Smithson's bequest were very definite. He presented them in his first annual report to the Board of Regents in the form of a plan or program of organization, which was adopted by the

Board on December 13, 1847. This program so clearly outlines what should be the proper object and aims of the new institution, and is so prophetic of its actual development that some extracts from it are of interest. A number of paragraphs of minor importance have been omitted.

INTRODUCTION

General considerations which should serve as a guide in adopting a Plan of Organization.

1. Will of Smithson. The property is bequeathed to the United States of America, "to found at Washington, under the name of the Smithsonian Institute, an establishment for the increase and diffusion of knowledge among men."

2. The bequest is for the benefit of mankind. The Government of the United States is merely a trustee to carry out the design of the testator.

3. The Institution is not a national establishment, as is frequently supposed, but the establishment of an individual, and is to bear and perpetuate his name.

4. The objects of the Institution are—1st, to increase—and 2nd, to diffuse—knowledge among men.

5. These two objects should not be confounded with one another. The first is to enlarge the existing stock of knowledge by the addition of new truths; and the second, to disseminate knowledge, thus increased, among men.

6. The will makes no restriction in favor of any particular kind of knowledge; hence all branches are entitled to a share of attention.

7. Knowledge can be increased by different methods of facilitating and promoting the discovery of new truths;and can be most extensively diffused among men by means of the press.

8. To effect the greatest amount of good, the organization should be such as to enable the Institution to produce results in the way of increasing and diffusing knowledge, which cannot be produced either at all or so efficiently by the existing institutions in our country.

. . . .

13. It should be recollected that mankind in general are to be benefited by the bequest' and that therefore all unnecessary expenditure on local objects would be a perversion of the trust.

14. Beside the foregoing considerations, deduced immediately from the will of Smithson, regard must be had to certain requirements of the act of Congress establishing the Institution. These are, a library, a museum, and a gallery of art, with a building on a liberal scale to contain them.

SECTION 1

Plan of Organization of the Institution in accordance with the foregoing deductions from the will of Smithson.

To increase knowledge: It is proposed—

1. To stimulate men of talent to make original researches by offering suitable rewards for memoirs containing new truths; and,

2. To appropriate annually a portion of the income for particular researches, under the direction of suitable persons.

To diffuse knowledge: It is proposed—

1. To publish a series of periodical reports on the progress of the different branches of knowledge; and,

2. To publish occasionally separate treatises on subjects of general interest.

DETAILS OF THE PLAN TO INCREASE KNOWLEDGE

I. *By stimulating researches.*

1. Rewards consisting of money, medals, etc., offered for original memoirs on all branches of knowledge.

2. The memoirs thus obtained to be published in a series of volumes, in a quarto form, and entitled "Smithsonian Contributions to Knowledge."

3. No memoir on subjects of physical science to be accepted for publication which does not furnish a positive addition to human knowledge, resting on original research; and all unverified speculations to be rejected.

. . . .

6. The volumes of the memoirs to be exchanged for the transactions of literary and scientific societies, and copies to be given to all the colleges and principal libraries in this country. One part of the remaining copies may be offered for sale, and the other carefully preserved, to form complete sets of the work, to supply the demand for new institutions.

7. An abstract, or popular account of the contents of these memoirs to be given to the public through the annual report of the Regents to Congress.

II. *By appropriating a part of the income annually to special objects of research.*

1. The objects and the amount appropriated to be recommended by counsellors of the Institution.

2. Appropriations in different years to different objects; so that in course of time each branch of knowledge may receive a share.

3. The results obtained from these appropriations to be published, with the memoirs before mentioned, in the volumes of the "Smithsonian Contributions to Knowledge."

4. Examples of objects for which appropriations may be made: (*a*) System of extended meteorological observations for solving the problem of American storms. (*b*) Explorations in descriptive natural history, and geological, magnetical and topographical surveys, to collect materials for the formation of a Physical Atlas of the United States. (*c*) Solution of experimental problems, such as a new determination of the weight of the earth, of the velocity of electricity and of light; chemical analyses of soils and plants; collection and publication of scientific facts accumulated in the offices of Government. (*d*) Institution of statistical inquiries with reference to physical, moral, and political subjects. (*e*) Historical researches and accurate surveys of places celebrated in American history. (*f*) Ethnological researches, particularly with reference to the different races of men in North America; also explorations and accurate surveys of the mounds and other remains of the ancient people of our country.

DETAILS OF THE PLAN FOR DIFFUSING KNOWLEDGE

I. *By the publication of a series of reports, giving an account of the new discoveries in science, and of the changes made from year to year in all branches of knowledge not strictly professional.*

1. These reports will diffuse a kind of knowledge generally interesting, but which at present is inaccessible to the public. Some of the reports may be published annually, others at longer intervals, as the income of the Institution or the changes in the branches of knowledge may indicate.

2. The reports are to be prepared by collaborators eminent in the different branches of knowledge.

3. Each collaborator to be furnished with the journals and publications, domestic and foreign, necessary to the compilation of his report; to be paid a certain sum for his labors, and to be named on the title-page of the report.

. . . .

II. *By the publication of separate treatises on subjects of general interest.*

1. These treatises may occasionally consist of valuable memoirs, translated from foreign languages, or of articles prepared under the direction of the Institution, or procured by offering premiums for the best exposition of a given subject.

2. The treatises should in all cases be submitted to a commission of competent judges previous to their publication.

3. As examples of these treatises, expositions may be obtained of the present state of the several branches of knowledge mentioned in the table of reports. Also of the following subjects, suggested by the Committee on Organization, *viz*: the statistics of labor, the productive arts of life, public instruction, etc.

The development of the Institution on this plan was made more difficult by the requirement of the act that the Institution should construct a building in which to install a library and collections of objects of nature and of art. It was found that by careful planning and because of the accumulation of interest on the original fund during the eight years that had elapsed since the fund was received, the building could be constructed without trenching on the original bequest, but the necessity of collecting a library threatened to make serious drains on the annual income. Henry never lost an opportunity to urge upon the Regents and through them upon Congress the propriety of relieving the Smithsonian Institution from the necessity of collecting an independent library. At the outset the Regents determined that half of the income should go to the library, but as the success of other parts of Henry's program became more apparent, the portion of the income allotted to the library was gradually reduced. By utilizing a system of exchanges with the Smithsonian publications, and by limiting the contents of the library largely to scientific periodicals and transactions of learned societies, the library was made to some extent to serve in the support of scientific research. At last in 1865, after the disastrous fire of that winter, Congress consented to the transfer of the Smithsonian collections, which by that time contained 40,000 volumes, to the Library of Congress, and the Smithsonian Institution was relieved from the necessity of a further accumulation of books. Such objects of art as the Institution possessed were transferred to the Corcoran Art Gallery. The museum still remained a charge upon the Institution, but for many years it has been supported by an independent appropriation. The fund was thus at last left free for use in the way proposed by Henry for the increase and diffusion of knowledge among men.

The publications of the Smithsonian Institution, which were planned by Henry, are contained in the series of the Annual Reports to the Board of Regents, the Smithsonian Contributions to Knowledge, containing memoirs on all sorts of scientific subjects and the Smithsonian Miscellaneous Collections, a most useful set of tables, collections of formulae, etc. The institution has thousands of correspondents in all parts of the world, and its publications go to all important libraries. As its funds have increased by other gifts, it has been able to extend its operations by supporting other enterprises, such as the Astrophysical Observatory.

Henry himself, in the earliest years of the Institution, developed a system of meteorological observations all over the country, largely by the help of volunteers. Out of this developed the system of predictions of storms, and of the weather in general, which soon became so important for our national life, that it was taken over by a branch of the government.

Henry perceived that one of the most important functions which could be performed by an Institution such as the Smithsonian would be the preparation of an Index of Scientific Literature. In no other way could the funds of the Institution serve better for the diffusion of knowledge. He found very soon that the available means would not be sufficient to provide for the formation of a general index for the scientific literature of the world, but he determined to make a beginning by constructing such an index for the science of America. For the larger project he undertook to enlist the cooperation of the British Association for the Advancement of Science. This Association received his proposals favorably and from the movement thus started, which was ultimately taken up by the Royal Society, came the grand catalogue of scientific papers published by that Society. In the preface of the first edition Henry's place as the originator of the project, which was thus brought to completion, was generously recognized.

Henry's activity was not confined to his work as Secretary. Most of his scanty leisure was devoted to the work devolving upon him as the Chairman of the Committee on Experiments of the Light-House Board. It was largely through his influence that the lenticular system of constructing lenses for lighthouses, invented by Augustin Fresnel, was introduced so rapidly into the lighthouses of the United States. He conducted elaborate experiments with the object of obtaining some substitute for sperm oil for use in the lamps, by which it was found that if properly heated, lard oil not only furnished a cheaper light than the increasingly expensive sperm, but a better light.

In the later years of his life, Henry devoted a great deal of time and labor to the investigation of fog signals, in the endeavor to decide which of the various instruments that were proposed for the purpose was the best. He was particularly interested in the curious phenomenon which was sometimes observed of the inaudibility of the signal within certain areas. This occurred when the vessel was approaching the signal with a following wind. At a distance the signal would be heard, it then might become inaudible on the deck while it still could be heard at the masthead; as the vessel approached the signal still nearer the sound could not be heard at all, until perhaps after several miles and when the vessel had approached within a few miles of the signal, the sound came out again in full force. Henry concluded that his observations could be reconciled with the theory of Stokes, that the sound waves were turned upward as they proceeded against the wind, to be deflected again downward at a greater distance because of atmospheric conditions. These observations occupied Henry in his summer vacations for more than ten years. The papers in which he described his work were never published by him in the Smithsonian Contributions but are contained in various volumes of the Reports of the Lighthouse Board.

Henry's services to the government in this capacity are well described by the report made by the Naval Secretary of the Lighthouse Board soon after Henry's death, to the Secretary of the Treasury. An extract from it is as follows:

> As Chairman of this committee, Professor Henry acted as the scientific adviser of the Board. But in addition it was his duty to conduct the experiments made by the Board, not only in the matter of original investigation, and testing of the material used, but in examining and

reporting on the models, plans, and theories, presented by others to the Board. The value of the services he rendered in this position is simply inestimable. He prepared the formula for testing our oils; he conducted the series of experiments resulting in the substitution of lard oil for sperm oil, which effected an immense saving in cost; and he also conducted the experiments which have resulted in making it possible to substitute mineral oil for lard oil, when another economy will be made. His original investigation into the laws of sound have resulted in giving us a fog-signal service conceded to be the best in the world. His examinations into the action of electricity, have enabled the Board to almost completely protect its stations from the effect of lightning. The result of his patient, continuous, practical experimentation is visible everywhere in the service. No subject was too vast for him to undertake; none too small for him to overlook. And while he has brought into the establishment so many practical applications of science, he has done almost as much service by keeping out what presented by others seemed plausible, but which on examination proved impracticable.

Every theory, plan, or machine, which was pressed on the Board, as for the interests of commerce and navigation, was referred to the committee on experiments, when it was examined by its Chairman, and was formally reported upon. If it had no practical value, the report on record simply stated the inexpediency of its adoption: but the Professor often verbally pointed out to the presenter, its fallacy; and sent him away—if not satisfied—at least feeling that he had been well treated. He thus prevented not only the adoption of impracticable plans, but avoided the enmity of their inventors.

Professor Henry made many valuable reports, containing the results of his elaborate experiments into matters which were formally referred to him, which are spread on the records of the Board; and the reports were drawn in such form that his suggestions were capable of and received practical application. But in addition to this, he was constantly extending his scientific researches for the benefit of the service in all directions. His summer vacations were as a rule passed in experimentation at the laboratory of the Establishment at Staten Island, on its steamers, or at its lightstations, pushing his inquiries to their last results. To experimentation in the interests of this service, Professor Henry seemed to give his whole heart. It appeared as if he never lost sight of the needs of the Establishment, and as if he never neglected an opportunity to advance its interests. In addition to his other duties, Professor Henry presided as Chairman of the Light-House Board for the last seven years at its weekly meetings, when he did much to infuse into the different members of the Board, his own spirit of labor for, and devotion to its interests.

The services described in this report were entirely gratuitous. In recognition of them, Congress after Henry's death granted a pension to his widow and children.

It is natural to compare Henry's career with that of his great contemporary Faraday. Both of them were born and brought up in humble circumstances. Both were apprenticed to a trade. Both of them were turned to an interest in science by the casual reading of a popular book: Henry by Dr. Gregory's lectures, Faraday by Mrs. Marcet's Chemistry. Henry's education at the Albany Academy was more advanced than any that Faraday received, but there was nothing in his life which corresponded to the long and intimate association enjoyed by Faraday with Sir Humphry Davy and with the other eminent men of science who frequented the laboratory of the Royal Institution. Henry's work was done under difficulties which Faraday was not called upon to face. Both of them were men of strong religious convictions and members of Christian churches. Both of them were loved as well as admired by all who knew them. Both of them worked successfully on the same subject and, as has been shown, their work was for some years intermingled. The similarity of their lives ceased when Henry took up the executive work of the Smithsonian Institution. In the years that followed Faraday pressed on to other magnificent discoveries while Henry was engaged in developing the methods by which another man's name would be honored. In one respect Henry was more fortunate than his contemporary, in that he preserved the full use of his faculties to the end of his long life. In a comparison of their work in the same field it cannot be doubted that while they were both industrious and successful in devising experiments and in the collection of facts, Faraday had the higher order of the scientific mind. His thoughts ran naturally to generalization. Henry was no generalizer. There is nothing in his work similar to Faraday's laws of electrochemistry or to his description of the magnetic or electric field by lines of force. Neither in quantity nor quality does Henry's work rank equal to that of Faraday. Yet he was an investigator of pronounced ability and deserves a distinguished place among the experimental philosophers by whom the science of electricity and magnetism has been advanced.

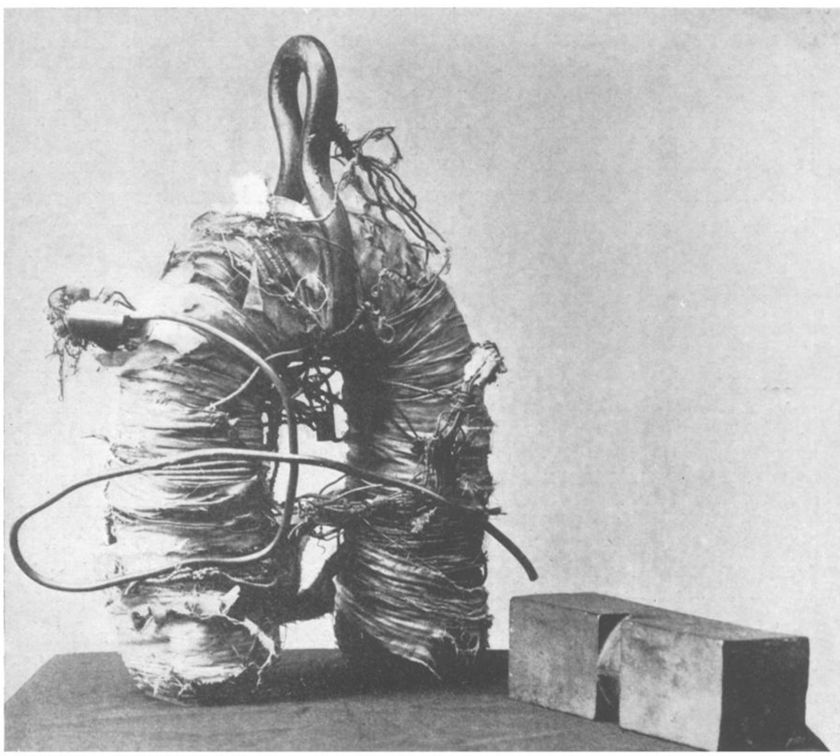

Fig. 2. One of Joseph Henry's electromagnets.

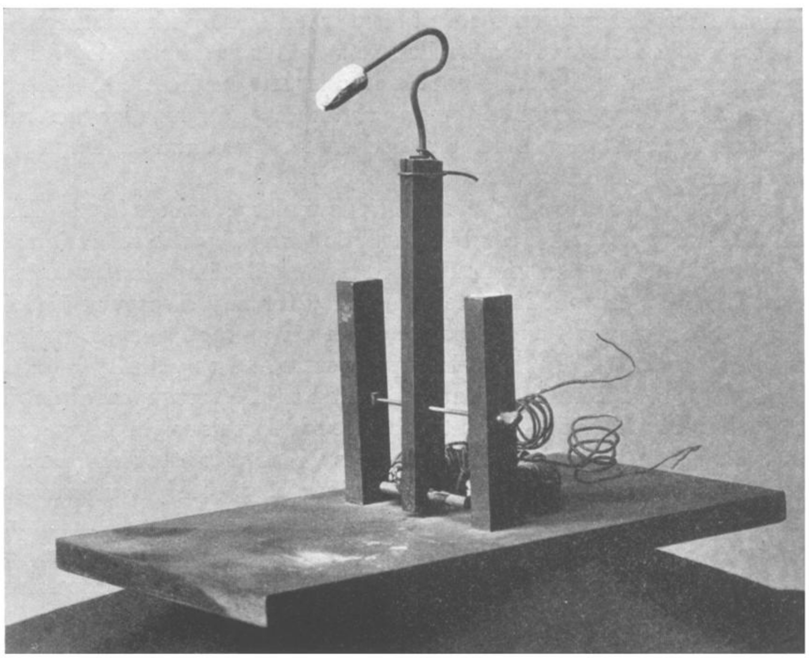

Fig. 3. Henry's electric bell.

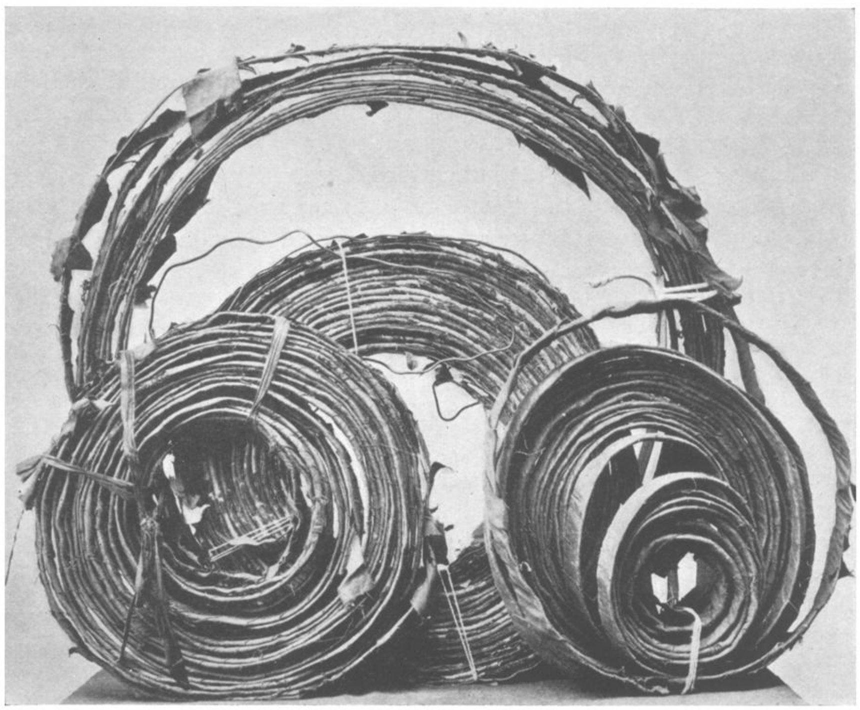

Fig. 4. Coils used by Henry in his experiments on electromagnetic induction.

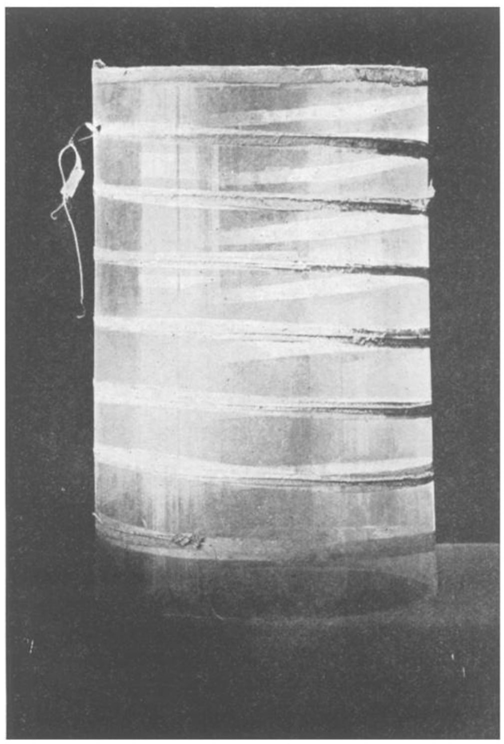

Fig. 5. Coil used by Henry to show the inductive action of the current produced by to an electrical discharge.