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THE WORK OF JOSEPH HENRY IN RELATION TO APPLIED SCIENCE AND ENGINEERING[1]

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THE pioneer work of Joseph Henry in physics, and especially in its department of electromagnetics, has justly claimed the principal attention of his biographers and students. Certain aspects of Henry's work in the physics of electromagnetic induction were the theme of that fine presentation last year by President J. S. Ames, of the Johns Hopkins University, in the first Joseph Henry lecture of this series. Henry also accomplished, however, so much in applied physics that without detracting in the least from his fame as a pure scientist and researcher in basic physics, it seems proper to consider, in this second Joseph Henry lecture, his achievements in relation to applied science and engineering.

[1] The second Joseph Henry Lecture, delivered before the Philosophical Society of Washington on April 23, 1932. The lecture was illustrated by lantern slides showing Henry's apparatus, as taken from authentic sources.

As it is sometimes difficult to distinguish between basic and applied science, when considering the manifold occupations and accomplishments of a scientific pioneer like Henry, we may be permitted to consider as basic those scientific studies directed to the development of a field of knowledge *per se;* and as applied science or engineering, those studies directed to utilities, as well as to the field itself. So interwoven, however, are basic and applied science, and especially in physics, that the distinction between them may sometimes be reduced to mere differences in the attitude of the researcher's mind. One and the same piece of scientific research may be regarded as either basic, or applied, or both, according as the researcher directed his mind to the field of knowledge itself or to its utilization, or to both.

Henry's accomplishments in applied science are notable in the following fields:

I. Civil Engineering.
   Surveying and Geodetics.
II. Electrical Engineering.
   (a) Lifting electromagnets.
   (b) Electromagnetic telegraphy.
   (c) Elementary electromagnetic motors.
   (d) Lightning protection.
   (e) Electro-ballistics.
III. Mechanical Engineering.
   (f) Building stone tests.
IV. Acoustical Engineering.
   (g) In buildings.
   (h) In fog-signalling.
V. Illumination Engineering.
   (i) In light-house development.
VI. Meteorological Engineering.
   (j) Forecasting from telegraph bulletins.

It may be noted that among the 148 publications appearing in the "List of Professor Henry's Scientific Papers," printed in the Annual Report of the Smithsonian Institution for 1878 and the *Bulletin* of the Philosophical Society of Washington, Vol. II, nearly forty relate to scientific applications.

Surveying and Geodetics

In 1825, New York State appointed commissioners to survey the route for a state road from the Hudson River to Lake Erie, a distance of over 500 km. Henry was appointed an engineer on this survey. The route he followed was from Kingston, near West Point, on the Hudson, to Portland Harbor on Lake Erie. He acquitted himself so well in this survey that an effort was made to have him appointed permanently as state engineer. In 1829, he read a paper,[2] published in the Transactions of the Albany Institute, which is a topographical report covering a considerable part of the state of New York, giving tables of distances and elevations along various routes. His paper gives a clear description of the topography of the country along these routes. It states:

> The elevations in Table No. 1, between the Hudson River and Bath, are from the survey of William Morell, Esq. The remaining elevations of this Table, as well as those in No. 2, are from the personal survey of the writer of this article.

These levelling surveys had to be carried over some very difficult stretches of country, including sections of what was, at that time, primeval forest. Henry seems to have taken so much interest in this work that it may have been a matter of good fortune for both basic and applied science, when he was diverted from the profession of engineering by the vacancy of the chair of mathematics and natural philosophy in the Albany Academy.

Electrical Engineering

The traction or sustaining electromagnet: Sturgeon, in England, had announced, in 1825, the production of the first horseshoe electromagnet. It consisted of a bar of soft iron bent into horseshoe form, insulated on its surface by a coat of varnish, and with bare copper wire wound over it in separate spires. When a voltaic current was passed through the copper wire, the horseshoe became magnetized, and would lift an iron rod laid across its poles.

The laws controlling the force of attraction between the electromagnet and its soft iron keeper, or armature, are complicated and were not worked out in detail for practical applications until many years later. They involve a combination of electric current in the electric wire circuit and of magnetic current or flux in the magnetic circuit.

Henry, experimenting with electromagnets at Albany, N. Y., in the years 1828–1831, succeeded in establishing certain fundamental principles, as to the conditions in both the electric and magnetic circuits, for securing the maximum attractive force from a given horseshoe electromagnet. At the same time, he greatly improved the winding on the magnet by using insulated wire in many close turns. At that time, of course, there were no instruments for measuring electric current. He made a series of electromagnetic measurements with three controlled elements, *viz.:*

> (a) the number and the size of the voltaic cells in the exciting circuit of the electromagnet.
> (b) the length of extra copper wire introduced into this circuit.
> (c) the number of series or parallel windings on the electromagnet.

Under these controlled variations, he measured the attractive force, in pounds weight, exerted by the magnet.

In cooperation with Dr. Ten Eyck, he showed, from a number of such measurements, that the greatest attractive force or lifting power[3] could be obtained from a horseshoe electromagnet by the use of a "quantity battery" together with a "quantity winding" on the magnet, provided that the battery and magnet were close together and connected by short lengths of wire. That is, the battery should have only one cell and its plates should be of large surface. The magnet windings should be connected in parallel. On the other hand, when the battery and magnet were

[2] "Topographical Sketch of the State of New York Designed Chiefly to Show the General Elevations and Depressions of its Surface." "Scientific Writings of Joseph Henry." I: 8–36, Smithsonian Institution Publication, 1886. *Trans.* Albany Inst., I: 87–112.

[3] "Scientific Writings of Joseph Henry." I:.37–53, Smithsonian Institution Publication, 1886. *Silliman's Am. Journ. Sci.*, 19: 400–408. Jan., 1831.

far apart and had to be connected by a long wire, the best arrangement for attractive force on the armature was to use an "intensity battery" and an "intensity magnet," *i.e.*, the cells of the battery should be connected in series, and also the windings of the magnet. He points out that this combination has a bearing upon the problem of an electromagnetic telegraph. If, however, an intensity magnet has to be used, with all its turns in series, then for best tractive effort an intensity battery should be placed in the circuit, whether the connecting wires between them are short or long.

All of these principles, enunciated by Henry, more than a hundred years ago, are still fundamentally correct. The terminology, however, has been greatly changed, partly through the widespread knowledge of Ohm's law ($I = E/R$) of current in an electric circuit. Dr. Ohm had already published, in Berlin, his essay containing that law[4] in 1827, but the publication received very little attention, and did not find its way into text books on physics until some twenty years later. It did not come into electrical applications until after 1840, in the early development of telegraphy, and after instruments had been produced for measuring electromotive force, resistance, and current. The above mentioned results which Henry published in 1831, were far in advance of the knowledge in electromagnetics at that time.

In one set of measurements he describes his electromagnet as made of a cylindrical bar of soft iron 1/4 inch (0.64 cm.) in diameter, wound with about 8 feet (2.4 m.) of insulated winding with perhaps 100 turns. When this winding was excited by one copper-zinc voltaic cell with plates of 28 sq. in. (180 sq. cm.) immersed in dilute acid, the weight lifted by the magnet was 4½ lbs. (2 kg.). When a length of 1060 feet (320 m.) of copper bell wire 0.045 inch (1.14 mm.) in diameter was inserted in the circuit between voltaic cell and magnet, the lifting power of the magnet fell to about half an ounce (14 gm.) The resistance of the length of copper specified would to-day be about 5.5 ohms; but at that date, when high-conductivity copper was not in demand, it may readily have been nearly 12 ohms.

With an intensity battery of 25 zinc-copper cells in series and with the same active area of plate surface in each cell as before, the magnet lifted 8 ounces (227 gm.), with the whole length (320 m.) of copper wire inserted in the circuit; so that changing from 1 cell to 25 cells, increased the lift from 14 gm. to 227 gm., with the whole length of wire included. Short circuiting the long copper wire, or connecting the 25-cell series battery to the magnet terminals, gave no increase in lifting power. Indeed the lifting power observed was somewhat less (7 oz. or 198 gm.). It will be remembered, however, that the plain zinc-copper battery of those days was subject to marked polarization and variation of electromotive force, while in action. The effect of changing the battery from one cell to 25 in series, increased the lift from 14 gm. to 227 gm., with the long wire in circuit; but with the long wire cut out, the lift fell from 2,000 gm. to 227 gm. This was the first published demonstration of the importance of using a series-connected, or intensity battery, to increase the tractive power of an electromagnet of many turns through a considerable length of external circuit.

Discussing the remarkable power of the intensity battery to overcome the effect of inserting the 320 meters of extra copper wire in the circuit, Henry remarks:

> On a little consideration, however, the above result does not appear so extraordinary as at first sight, since a current from a trough possesses more "projectile force" to use Prof. Hare's expression, and approximates somewhat in intensity to the electricity from the common machine. May it not be a fact that the galvanic fluid, in order to produce its greatest magnetic effect, should move with a small velocity . . . ? . . . 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.

Here Henry uses the term "projectile force" to designate what we call to-day "electromotive force" and "velocity of magnetic fluid" for what we now call "current strength." He is evidently not far from a conception of Ohm's law, which had already been formulated mathematically by Ohm four years before. By the term "trough" in the above quoted passage, Henry evidently means a series-connected battery, with the elements arranged in the form of a trough. Also by the term "common machine" he doubtless refers to either the frictional or the induction electric machine, which were the only electric generators known, prior to Volta's discovery, in 1800, of the voltaic pile.

In the same publication, Henry goes on to describe the construction of a larger electromagnet, a model of which, kindly loaned to us by the Smithsonian Institution from its museum, is shown here this evening. The magnet had a winding of 9 coils of insulated copper wire arranged to be connected either in series or in parallel combinations. The total weight of the magnet was 21 pounds (9.5 kg.). It was excited by one zinc-copper dilute acid cell with con-

[4] "Die galvanische Kette mathematisch bearbeitet." Georg Simon Ohm, Professor of Physics at Munich. Berlin, 1827.

centric plates. The effects were tried of various winding combinations on the sustaining power of the magnet. The maximum was reached at 750 pounds (340 kg.), when all the windings were connected in parallel, or as a "quantity" winding. The magnet thus lifted more than 35 times its own weight, with the aid of a single exciting cell, a very remarkable achievement for the year 1831.

In a communication to *Silliman's American Journal of Science*[5] in April, 1831, Henry describes a yet larger horseshoe electromagnet, constructed for Yale University. It weighed 59½ pounds (27 kg.) without its multiple-coil winding. Excited with a single zinc-copper dilute acid cell, it supported a weight of 2063 pounds (937 kg.).

Electromagnets for raising and carrying masses of iron are in fairly extended engineering use at the present day, and Henry's pioneering work at the Albany Academy from 1827 to 1832 clearly pointed the way to that electrical application.

The electromagnetic bell signalling instrument here shown, from the Smithsonian Museum collection of Henry apparatus, is a replica of an apparatus made and used by Henry, in 1832, for sending audible electromagnetic signals through a wire more than a mile in length. This apparatus is not referred to in Henry's paper of 1831, but appears in Henry's statement to the Board of Regents of the Smithsonian Institution for 1857, together with testimony to show that the instrument was exhibited in 1832, at the Albany Academy.[6]

> "I arranged around one of the upper rooms in the Albany Academy a wire of more than a mile in length, through which I was enabled to make signals by sounding a bell. The mechanical arrangement for effecting this object was simply a steel bar, permanently magnetized, of about ten inches in length, supported on a pivot, and placed with the north end between the two arms of the horse-shoe magnet. When the latter was excited by the current, the end of the bar thus placed was attracted by one arm of the horse-shoe and repelled by the other, and was thus caused to move in a horizontal plane and its further extremity to strike a bell suitably adjusted."

The original Henry instrument is kept in the Palmer Laboratory Museum at Princeton, where Henry set it up, and is reported on good authority to have been used as a signalling device, in his house on the Princeton University campus, operated by electric current from his laboratory, probably in the basement of Nassau Hall.

Henry declared that he never in his life filed an application for a patent of invention. In this technical sense, therefore, he was not an inventor; but in a broad sense of the term, he was undoubtedly a great inventor; because in making researches in basic science—his selected field of work—he often indicates through his writings that he realized from time to time possible applications for his discoveries, while leaving to others the tasks of introducing them into industrial service. He always admitted that Morse was the inventor of the electric telegraph bearing that name, but Henry has recorded the following claims:[7]

> "From a careful investigation of the history of electro-magnetism in its connection with the telegraph, the following facts may be established:
>
> (1) Previous to my investigations, the means of developing magnetism in soft iron were imperfectly understood, and the electro-magnet 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 must be used to receive the current.
>
> (3) I was the first to actually magnetize a piece of iron at a distance, and to call attention to the fact of the application of my experiments to the telegraph.
>
> (4) I was the first to actually sound a bell at a distance by means of the electro-magnet.
>
> (5) The principles I had developed were applied by Dr. Gale to render Morse's machine effective at a distance."

There can be no doubt that Henry's electromagnetic researches found abundant application in the magnetic telegraph.

Voltaic-battery mechanism for series-parallel connections: Henry published, in 1835, an illustrated description of a machine which he designed and constructed at Princeton for swiftly changing a voltaic battery of 88 cells, from series to parallel combinations, so that they might be, in the extreme cases, either all in series or all in parallel.[8] The various pairs of plates were held in a rigid wooden frame, and each plate had a little metallic cup fastened to it for holding a small quantity of mercury. Metallic bars of suitable size and shape, served to connect the cells in series or in parallel.

[5] "An account of a large electromagnet, made for the laboratory of Yale College." "Scientific Writings of Joseph Henry." I: 50–53, Smithsonian Institution Publication, 1886.

[6] "Statement in relation to the history of the electro-magnetic telegraph." Smithsonian Annual Report for 1857, pp. 90–106. "Scientific Writings of Joseph Henry." II: 420–437, Smithsonian Institution Publication, 1886.

[7] "Scientific Writings of Joseph Henry." II: 435–436, Smithsonian Institution Publication, 1886.

[8] "Description of a galvanic battery for producing electricity of different intensities." "Scientific Writings of Joseph Henry." I: 80–86, Smithsonian Institution Publication, 1886. Trans. Am. Phil. Soc., 5: 217–222. Jan. 1835.

The same plan in essentials, is very generally employed to-day with storage-battery installations for charging them in parallel and discharging them in various series combinations for high-tension service. Henry's apparatus was thus a pioneer form of voltaic-battery engineering design.

Electromagnetic engine or early form of electric motor: On the table, is the replica of Henry's early form of reciprocating motor driven by voltaic-battery power. This replica is also loaned by the Smithsonian Museum. The original is preserved with the Henry apparatus at Princeton University.

The little engine is described by Henry in a letter to the editor of *Silliman's American Journal of Science*[9] published in July, 1831, in the following terms:

> "Sir: I have lately succeeded in producing motion in a little machine by a power, which, I believe, has never before been applied in mechanics—by magnetic attraction and repulsion.
>
> Not much importance, however, is attached to the invention since the article, in its present state, can only be considered a philosophical toy; although, 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. But without reference to the practical utility, and only viewed as a new effect produced by one of the most mysterious agents of nature, you will not, perhaps, think the following account of it unworthy of a place in the *Journal of Science.*"

The apparatus consists of a pair of vertical permanent magnets, which, in modern parlance, are the *field magnets* of the little machine. As described in the paper, their north poles are uppermost. A soft iron bar, pivoted about a horizontal axis, and wound with insulated wire, is free to oscillate over a certain range under the magnetic forces of the upright permanent magnets. This oscillatory electromagnet corresponds to the *armature* of a modern direct-current motor. At the free ends of the rocking armature are stiff projecting copper wires, arranged to dip into mercury cups at each end in such a manner that the current from a voltaic cell is caused to reverse the magnetization of the rocker bar near the end of each stroke, and so reverse the magnetic forces on the rocker bar. In this rocking commutator, we have the precursor of the *rotating commutator* of the modern motor.

Henry thus produced what was probably the first electric motor device, although in the progress of the art, its reciprocating motion had to be converted into rotary motion, before practical success was attained with motors.

Lightning protection: Henry was a close observer of atmospheric electric phenomena, and contributed a number of articles to the literature of the subject at different times. He also, however, formulated a set of rules or directions[10] to be followed for the protection of houses from lightning. These rules would probably be regarded as good engineering specifications against lightning damage at the present date.

Electro-ballistics: In 1843, Henry communicated to the American Philosophical Society, a paper[11] "On a new method of determining the velocity of projectiles." He describes a chronograph drum, revolving at a uniform speed of at least 10 turns per second, so as to permit of high-speed ballistic records upon its surface. Two copper wire screens are placed successively in the path of the projectile whose speed is to be measured. The projectile cuts the wire in the screens so as to interrupt a voltaic circuit through each, at the instant of its passage. These circuit interruptions are automatically recorded on the surface of the drum, either by the deflection of magnetic needles, or by electric sparks puncturing a sheet of ruled paper on the drum. The sparks are caused by induction coils.

The method and system, as described, constitute an electrical-engineering invention in ballistics.

MECHANICAL ENGINEERING

Testing of building materials: In August, 1855, Henry read a paper before the American Association for the Advancement of Science, "On the mode of testing building materials." The President of the United States had appointed a commission of five persons in 1851, "to examine the marbles which were offered for the extension of the United States Capitol" at Washington. Another commission of three persons was appointed in 1854, to repeat and extend some of the experiments. Henry was a member of both commissions and evidently took upon himself a large share of the experimental work.

Small cubical blocks of the marbles to be compared were tested in a press for resistance to crushing. A long series of tests, made in this manner, brought out some remarkable and unexpected results. It was shown that when the crushing stress was exerted on the blocks with thin sheets of lead inserted between the press plates and the pressed block surfaces, the blocks gave way at about half of the pressure they

9 "On a reciprocating motion produced by magnetic attraction and repulsion." "Scientific Writings of Joseph Henry." I: 54–57, Smithsonian Institution Publication, 1886.

10 "Construction of Lightning Rods," "Scientific Writings of Joseph Henry." II: 398–402, 1859, Smithsonian Institution Publication, 1886. Also "On the Protection of Houses from Lightning," *Proc.* Am. Phil. Soc., June 20, 1845.

11 "Scientific Writings of Joseph Henry." I: 212–215, Smithsonian Institution Publication, 1886. *Proc.* Am. Phil. Soc., 3: 165–167. May, 1843.

could sustain when the lead sheets were not used. The account is, in effect, an engineer's report.

ACOUSTICAL ENGINEERING IN BUILDINGS

In the *Proceedings of the American Association for the Advancement of Science*[12] for August 1856, Vol. X, pp. 119–135, Henry published a remarkable paper, "On acoustics applied to public buildings." He states that Prof. Bache and he had directed attention to the subject of acoustics as applied to buildings, when the President of the United States had referred to them the plans for the construction of rooms in the new wings of the Capitol at Washington. They visited, with this object, the principal halls and churches in Philadelphia, New York and Boston. The final plans of the new rooms were approved and successfully built.

They also had designs prepared for the new lecture hall of the Smithsonian Institution, and incorporated into them various acoustic principles their researches had brought out. These researches are most interestingly described in the paper. Henry, in this research, was an acoustical engineer, with his aim directed on improving the acoustic properties of the lecture hall. He was, however, also a pioneer investigator of interior acoustics, considered as a basic science. He says (p. 419):

> "These researches might be much extended; they open a field of investigation equally interesting to the lover of abstract science and to the practical builder."

In this passage is revealed that remarkable duality of Henry's mind which appears again and again in his writings. He studies a subject for a utilitarian purpose as an engineer, and enriches its basic science, while at another time he studies a new field as a physicist, and suggests intuitively to the reader where practical applications are likely to be found. He was *par excellence* a combination of physicist and engineer.

The acoustic properties of the Smithsonian lecture hall appear to have been very satisfactory and to have endorsed the special acoustic features introduced into its construction.

FOG-SIGNAL ACOUSTICS

Congress established the U. S. Lighthouse Board in 1852, with Henry as one of its members. Later, as chairman of its Committee on Experiments, he directed, in 1865, a series of acoustic researches on fog signals, that were not only of basic scientific importance, but also of great engineering value. He showed experimentally that beyond relatively short distances, artificial sound reflectors were of no avail. To eliminate the personal equation in acoustic observations of this kind, he describes an artificial ear or "phonometer," for making feeble sound waves perceptible to the eye.

These researches of Henry appeared as unsigned reports of the Light House Board, but were subsequently included in his published papers. These reports contain comparisons of the acoustic ranges attained, under normal atmospheric conditions, by steam whistles, trumpets, and sirens. Such comparisons were made over short ranges by phonometer, and over long ranges by ear, on small vessels making exploratory trips for purposes of the test. They are acoustic-engineering reports of great interest. They were made at various times from 1865 to 1877.

In the course of these tests, Henry closely investigated the abnormal conditions of the appearance of fog signals at shorter and longer ranges, with their concurrent disappearance over a certain intermediate range, or belt of silence. These occasional but practically important acoustic anomalies, were referred to by Henry in two presidential addresses before your Society, one[13] on December 11th, 1872, when Dr. Tyndall was present, and the other[14]—his last address to you—on November 24th, 1877.

ILLUMINATING ENGINEERING

Lighthouse development: In the Report of the Lighthouse Board for 1875, pp. 86–103, Henry points out that in 1852, when the Board[15] commenced its operations, sperm oil was the fuel generally employed. The steadily rising cost of sperm oil made it desirable to find some less expensive substitute. A series of experiments was commenced with lard oil, which was then much cheaper, but not regarded as capable of use in powerful lamps.

Commencing with a pair of small conical lamps having "single-rope," as distinguished from tubular wicks, one burning sperm oil and the other lard oil, the two commenced nearly at equality of candle-power, by photometer; but after burning for three hours the lard-oil lamp fell to about one-fifth of the photometric power of the sperm-oil lamp. On analyzing the reasons for the falling off in candle-power of the lard-oil flame, Henry was led to the conclusion that the capillary flow or liquidity of the lard oil in

12 "Scientific Writings of Joseph Henry." II: 403–421, Smithsonian Institution Publication, 1886.

13 "Remarks on Some Abnormal Phenomena of Sound," Smithsonian Report 1878, pp. 490–496.

14 "The Method of Scientific Investigation and its Application to Some Abnormal Phenomena of Sound," Bull. Phil. Soc. Washington, 2: 162–174.

15 "Scientific Writings of Joseph Henry." II: 477–510, Smithsonian Institution Publication, 1886.

the wick is relatively defective. This, however, was found to be affected by the temperature of the oil, so that by raising the temperature of the lard oil to about 250° F., the liquidity of the lard oil became greater than that of the sperm oil. When, therefore, the conditions of oil feeding through the wick of a large burner raised the temperature sufficiently, the lard oil should be capable of competing on favorable terms.

After further preliminary trials with larger tubular-wick burners, the experiment was carried to Cape Ann, Massachusetts. Here were two twin lighthouses, only 275 meters apart. One of these was operated with sperm oil, as usual, and the other with lard oil, each lamp being so trimmed as to exhibit its greatest capacity.

> "It was found by photometric trial that the lamp supplied with lard oil exceeded in intensity of light that of the one furnished with sperm oil. The experiment was continued for several months, and the relative volume of the two materials carefully observed. The quantity of sperm oil burned during the continuance of the experiment was to that of lard oil as 100 is to 104."

A long series of photometric measurements at Boston is then described, with the substitution of the Bunsen grease-spot photometer head for the earlier Rumford shadow comparator. An improved photometer for measuring the candle-powers of burners using different oils, was also set up at the Smithsonian Institution.

As a result of improvements in lamp mechanism, as well as in the substitution of lard oil for sperm oil in all of the lighthouses of the United States, a great reduction was effected by 1866, in the annual cost of lighthouse oil.

This published account of lighthouse research is a fine engineering report, containing many basic scientific suggestions of great interest. Later on, the price of lard oil began to rise and a new series of researches was undertaken leading to the introduction of mineral oil, which was attended at first by a number of special difficulties.

METEOROLOGICAL ENGINEERING

Applications of Telegraphy: In our daily contact with the service of the Weather Bureau, which displays coastal storm warnings in advance of expected heavy gales, and furnishes daily weather forecasts, with maps, showing the principal meteorological conditions, at a given hour each day, over the North American continent, it is hard for us to realize the corresponding conditions that existed, say, in 1845, before Henry left Princeton and when there was no way of foretelling the approach of a coming big storm, except such as could be guessed by any single observer at one spot, and before the general laws of revolving storms had been arrived at.

Henry devoted much time to the study of meteorology, which evidently exerted a fascination for him throughout his life. The first page of his published papers gives abstracts of his first known scientific contributions (Proceedings of the Albany Institute in 1825 and 1826)—communications dealing respectively with "Chemical and mechanical effects of steam" and "Refrigeration by rarefaction of air." Among his published papers are 38 that bear by title upon meteorology. According to the account by his biographer, W. B. Taylor, read before this Society, October 26th, 1878, Henry's last feeble utterance on his dying day, May 13th, 1878, was a meteorological[16] enquiry.

Henry's early studies of weather, when he was at Albany, convinced him of the importance of securing simultaneous observations of barometric pressure, air temperature and humidity, wind velocity, cloud conditions and precipitation, at as many different stations as possible. In 1849, while the telegraph system of the country was only a few years old, it was organized with the aid of voluntary observers into a network by which a weather map could be made up each day at the Smithsonian Institution. Henry urged that every telegraph operator, coming on duty at a certain morning hour, should open with a definite meteorological message. This plan manifested its utility, but placed too heavy a burden on the Institution. In 1870, a meteorological office was established by the Government under the Signal Office of the War Department. This office was finally transferred to the Weather Bureau, created in 1891, under the Department of Agriculture. The early development of the Weather Bureau, was thus a telegraph-engineering development due to Henry's persistent labors in meteorology.

CONCLUSIONS

From what has been above excerpted from Henry's writings, it will be seen that this many-minded man, who made so many notable contributions to basic science, also contributed much to applied science.

When, therefore, it is justly claimed for Joseph Henry that he was a scientist-discover, writer, organizer, and administrator, it can be confidently added that he was also an inventor and engineer.

[16] "A Memoir of Joseph Henry," A sketch of his scientific work by William B. Taylor. Read before the Phil. Society of Washington, October 26, 1878, pp. 230–268. Phila., 1879. Smithsonian Coll., 21: 360.