Journal of the Washington Academy of Sciences,
Volume 82, Number 3, Pages 111–131, September 1992

Joseph Henry's 1842 and 1843 Out-of-Doors Electrical Transmission Signal Experiments

Albert Gerard Gluckman

Institute for Physical Science and Technology, University of Maryland,
College Park, Maryland 20742

ABSTRACT

Ever since G. Marconi first perfected his radio transmission apparatus in 1896, there has been controversy[(a)] as to whether Prof. Joseph Henry had transmitted and detected wireless electrical signals at a distance in 1842 and 1843. Evidence is presented to show that these signals were produced by a transient electromagnetic field alternating at about 3.5×10^5 Hz (i.e., cycles per second).

I discuss both the unpublished recorded and published evidence of Prof. Henry's out-of-doors electrical signal transmission experiments of October 1842 and October 1843. Mention is made of the destruction by fire of his records in January of 1865, and of the later published remarks about Henry's experiments made by Ernest B. Rutherford in 1894. I discuss the wiring of Henry's primary and secondary circuits, and the construction of his magnetic coil signal detector that he attached into the loop of the secondary wire.

1. *Introduction.* (a) Recorded and published evidence of signal transmission. On October 6, 7, and 8, 1842, Prof. Joseph Henry of the College of New Jersey (now Princeton University) conducted a series of outdoors electrical ex-

---

[a] Refer to:

(1) J. S. Ames, **The Discovery of Induced Electric Currents.** vil. I. Memoirs by Joseph Henry, American Book Company, New York, Cincinnati, Chicago. (LC: QC631.A51) See p. 107 for pertinent remarks:
(2) J. S. Ames, *Certain Aspects of Henry's Experiments on Electromagnetic Induction,* Science, 75, no. 1934 (Friday, January 22, 1932) pp. 87–92. See especially page 91.
(3) W. F. Magie, *Joseph Henry,* Reviews of Modern Physics, vol. 3 (October 1931) pp. 465–495.

In a speech at a meeting of the American Institute of Electrical Engineers arranged in his honor at the old Waldorf-Astoria hotel in New York City on January 13, 1902, G. Marconi said:

> "I have built very largely on the work of others, and before concluding I would like to mention a few names. I may miss a few of them, but I would like to mention Clerk Maxwell, Lord Kelvin, Professor Henry and Professor Hertz."

This quotation was taken from page 116 of **Marconi: The Man and His Wireless** by O. E. Dunlap, Arno Press and The New York Times (1971) New York; L.C. call no. TK 5739.M3 D8 1971.

periments on the grounds of what was then called the "back campus" behind Nassau Hall. In his laboratory notebook for the date October 7, he recorded separation of his primary and secondary circuits at a distance of 165 feet, after having made successive increases in distance in the course of these experiments. Furthermore, he recorded in the final three experiments on Oct. 8, that

> "the whole parallelogram formed by the secondary wire, was carried backward, so that the farthest side was in the field beyond the Society halls" [1 and 7].

It is inferred from this remark in his record of experiments, and from the later oral communication made at the October 21 meeting of the American Philosophical Society, that the distance between the primary wire and secondary wire in this final experiment of October 8, 1842, was more than 220 feet. The entry recording this experimental result is:

> "Prof. Henry . . . had succeeded in magnetizing needles by the secondary current in a wire more than two hundred and twenty feet distant from the wire through which the primary current was passing, excited by a single spark from an electrical machine." [2]

Exactly one year later, on October 16th through the 19th, 1843, Prof. Henry renewed his electrical signal transmission experiments. This series of experiments was made on the lawn of the front campus.

(b) Destruction of recorded evidence of signal transmission. On the bitter cold day of January 24, 1865, a fire in the old red brick Smithsonian building on the Mall in the city of Washington (caused by some workmen making repairs on the building), destroyed

> "a large number of papers and scientific notes of the Secretary [Prof. Henry]; [and] a series of diaries. . . . This [was a] truly 'irreparable loss' of original notes of many series of experiments . . . running back for thirty years, . . . and of which but few had been published even by results". [3, 4.i]

H. C. Cameron, who was a student of Prof. Henry, and later, himself a Professor at Princeton University, in his later years verified this loss with his remembrance [4.ii] that

> ". . . the record of those experiments perished in the flames when a portion of the Smithsonian building was burned. . . ."

In addition, Henry himself wrote in 1849 in a letter to S. B. Dod and quoted by Dod in his "Discourse" [4.vii]

> "Since my removal to Princeton [in November of 1832 from Albany, New York] I have made several thousand original investigations on electricity, magnetism, and electro-magnetism, bearing on practical applications of electricity, brief minutes of which fill several hundred folio pages. They cost me years of labor and much expense."

Unfortunately, because these records of his experiments no longer exist, we lack the quantative details as well as a more definite description of the layouts (especially with regard to the insulation of the secondary circuits) of these electrical experiments; and an analysis of this lack of detail will be made.

(c) Analysis of existing publications and records of signal transmission. I propose to examine the remaining evidence left to us by Prof. Henry that he had recorded in his laboratory note book [1 & 7] in October of 1842 and October of 1843, in which he described the establishment of alternating currents in a secondary circuit wire in out-of-doors experiments. The existing record will be examined (along with information gleaned from maps[b] of the grounds of the old College campus in order to estimate the approximate locations of his wire arrangements). This visualization will be helpful in understanding and in determining whether he transmitted and detected (by observation of the magnetic state of a steel needle) the inductive effect of electromagnetic waves on the wire conductor, or whether he detected the effect of a ground current and ground return. The written evidence is clear for all to see that Henry hypothesized that electric effects could be propagated as a wave in an elastic aether, and further, that he called distant electric effects dynamic induction-at-a-distance because they occurred during the passage of time. I add at this point, that Michael Faraday went a step further than Henry in Faraday's brief Note **Thoughts on Ray-vibrations** (in 1846), when he hypothesized that an electric aether was not necessary to explain the transmittal of electromagnetic action.

Faraday's comments which set him apart from Henry on this Philosophical interpretation are recorded in Appendix I.

Henry had experimented with inductive effects at a distance from lightning as early as the year 1840. In the experiments examined in this paper, he used the same wire coil that he had used in his "Induction from a thunder cloud" experiments of June 10, 1842. In the experiments of October 1843, that are also examined in this treatise, he used the same coil as well as five other ones individually as part of his detector. During his experiments of June 2, 1842, at his study at home, he observed inductive effects from lightning at a distance of 20 miles, a

[b] These maps are:

(1) *Fire Map of Mercer county* (1890) page 88B. Scarlett & Scarlett, Newark, N.J., LC: G1258.M4S4 1890 folio.
(2) *Facilities Survey Map of the old Princeton University campus (circa 1904),* Office of the Vice President for Facilities, The MacMillan Building, Princeton University. This map was donated to The Joseph Henry Papers of the Smithsonian Institution. Washington, D.C.
(3) *Atlas of the City of Trenton and borough of Princeton, N.J.* (1905) Plate 22, A. H. Mueller & Co., 530 Locust St., Philadelphia, LC: G1259.T7L3 1905 folio.
(4) *The Campus of Princeton University from the Northwest* (1952) Princeton University Press, LC: G3814.P9 1952.S5.

distance which he could determine by comparing the time of the flash to the time he heard the thunder peale.

Many years afterward, in his publication of 1894, Ernest B. Rutherford [5] published the following discussion concerning the magnetization of steel needles under high frequency discharges; and in this discussion, he acknowledged Prof. Henry's prior studies on the magnetization of steel needles. After citing the researches of J. J. Thomson,[c] J. Trowbridge,[d] and Andrew Gray,[e] appertaining to magnetization of iron from high frequency discharges, he wrote:

> "In order to investigate the effect of 'magnetic penetration' in iron for fields varying very much more rapidly than could be obtained with the use of the 'time apparatus', the readiest means to hand for obtaining a very rapid oscillatory current was the ordinary leyden-jar discharge."
>
> "The subject of the magnetization of iron in these fields has been very little touched upon since the time that Henry experimented on the effect of leyden-jar discharges on the magnetization of steel needles."
>
> "In the experiments that follow it will be shown that iron is strongly magnetic in rapidly-varying fields, even when the frequency is over 100,000,000 per second."

In an 1896/1897 paper [6], Rutherford wrote in his introductory remarks that:

> "THE present paper deals with the subject of the magnetization of iron by high-frequency discharges, and the uses of magnetized steel needles for detecting and measuring currents of very great rapidity of alternation."
>
> "It will be shown that these magnetic detectors offer a very simple means of investigating many of the phenomena connected with high-frequency discharges, and may be used in ordinary Leyden jar circuits, but they also offer a sensitive means of detecting electrical radiation from Hertzian vibrators at long distances from the vibrator."
>
> . . .
>
> "The magnetization of steel needles when placed in a spiral through which a Leyden jar discharge was passed has long been known."
>
> "In 1842 Professor HENRY was led to suspect from the anomalous magnetization of steel needles that the Leyden jar discharge was oscillatory."[f]

---

[c] *Recent Researches,* p. 322; and *Philosophical Magazine* (1891) p. 457.

[d] 'Damping of Electric Oscillations', *Philosophical Magazine,* (December 1891).

[e] First edition: **The Theory and Practice of Absolute Measurements in Electricity and Magnetism** (1884) 2 volumes. Second edition: **Absolute Measurements in Electricity and Magnetism** (1889) Macmillan and Co., London & New York.

[f] These particular experiments done by Henry were antecedent to his out-of-doors transmission (i.e., electrical signal) experiments described in this paper. For particular information about the works of Abria and several others on steel needles, refer to A. G. Gluckman, *A brief Overview of the Historical Progress of Joseph Henry's Studies concerning Alternating-Current Phenomena,* Research Notes and Memoranda of Applied Geometry for Prevenient Natural Philosophy, POST-RAAG Reports, No. 199 (March 1986) pp. 1–55. (LC: Q1.R45 no. 199). In Europe, a copy may be read at the Science Museum library at South Kensington, London, or else at the library of the British Museum on Great Russell street, London.

See also: A. G. Gluckman, **The Discovery of Oscillatory Electric Current,** Journal of the Washington Academy of Sciences, **80,** no. 1 (March 1990) pp. 16–25; **Corrigenda,** J.W.A.S., **80,** no. 4 (December 1990) p. 187; and **Corrigendum,** J.W.A.S., **81,** no. 1 (March 1991) p. 43.

The Experiments of October 1842

2. ***What is known about the preparation of the primary circuit arrangement (for the transmission experiments) by Prof. Henry on October 6, 1842.*** **(a) The wiring of the primary and secondary (i.e., 1^0 and 2^0) circuits.** The principle source of the descriptions of these induction-at-a-distance experiments (that is, induction of a current in a wire) by Prof. Henry is chronicled in his own handwriting in his surviving laboratory records. [1] Diagram 1 shows the approximate layout of the wire arrangements for Henry's 1842 experiments in the old back campus. The layouts of the parallelogram-shaped circuits are not shown because of the lack of positional information.

A few days prior to October 6th, Prof. Henry arranged as his primary, a copper wire (400 feet in length and $\frac{1}{20}$th of an inch in diameter) to snake its way through the windows of (1) Philosophical Hall (since demolished), and from there into (2) Nassau Hall, and into (3) his residence where Prof. Henry had his study. At the windows of these buildings, the copper wire was supported by using insulating silk ribbon that was fastened to the sides of these windows.

> "I made an arrangement a few days since of a long wire, extending from the Electrical machine in philos. Hall, to my study on the opposite side of the campus. The wire passed diagonally across the large lecture room to the south west window facing the library and thence to the southern most window of the two upper ones of the East end of the college, to the door of my study."

The locations of these windows are depicted in diagrams 1 and 2 of the old campus.

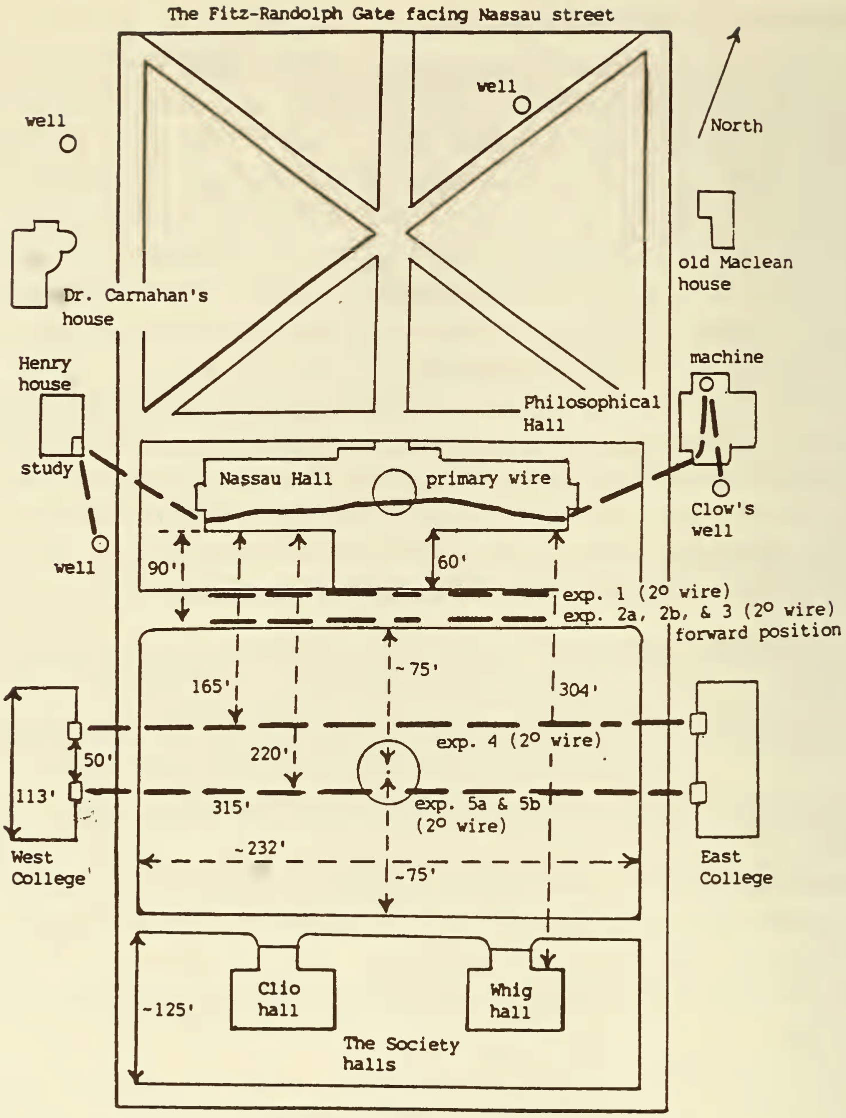
On the morning of October 6, the end of the wire next to Prof. Henry's study, was grounded by means of a connection to another copper wire that was already attached in the well just outside his study. This attachment in the well was already there from experiments with atmospheric electricity made about two years earlier.

> "This morning I completed a current with this wire and the ground by plunging the end next to my study into the well, or rather by connecting it with the wire which is already in the well for the experiments on atmospheric elec.. . . ."

Thus, the other end of the wire was attached to a length of copper wire which was securely connected (and grounded) into Mr. Clow's well, and weighted with lead. Earlier, on June 10, 1842, Henry [1 & 7] described the placement of the wire connection in the water well next to his house.

"I . . . passed the lower extremity [of the bell size[g] copper wire] into the

[g] Copper wire of the size used to ring church bells, hence the name bell wire, which was 0.05 of an inch in diameter (American manufacturing standard size 16). Modern American gauge size 16 is 0.0508 inches in diameter.



<u>Legend</u>

55' assumed from mid-door to mid-door of the East and West College buildings

the helix in the 2° wire had 45 turns in each of 6 layers (strata)

experiments 1, 2a, 4, 5a, had 3 charged jars in 1° circuit as the current source

experiments 2b and 5b had 1 jar in the 1° circuit as the current source

experiment 3 used a single spark thrown from the electrostatic machine as the current source

Diagram 1. Sketch of the campus of the College of New Jersey at Princeton, circa 1842, showing approximate locations of wiring

> water of the well. This was effected by fastening a cylinder of lead to the end of the wire, and passing this through a hole in the cover[h] near the [hand] pump of the well."

Prof. Henry recorded on October 6th that his primary circuit with ground return via the connections in the two water wells, transmitted a test current that tested the wire connections. He described this experimental demonstration in the following [1 & 7] words:

> "Whence small galvanometer of fine wire was placed in the circuit in my study and a small electrometer, consisting of a plate of zinc of about a tenth of an inch in width and the end of the wire ($\frac{1}{20}$[?th?] an inch) for a negative element, the needle [of the galvanometer] was deflected showing that this small galvanic [d.c.] arrangement was sufficient to send a current through [?left blank by Henry?] feet of wire and [?left blank by Henry?] feet of earth."

In his laboratory note book record [1] for that day he wrote:

> "Two poles supported by tripods formed of long slats of boards, were placed upright in the back campus, and over the tops of these a part of a wire was stretched parallel to the wire, through the old college, and of a length equal to the whole breadth of the campus. This wire was continued backward on each side, until it extended to the two halls, it then crossed over with the two ends united, so as to form a complete parallelogram."

(b) A magnetometer for measuring the strength of magnetism and polarity due to the transmitted signal, described by Prof. Henry on June 2nd 1842. [1 and 7; pp. 275–276] **Method given by Prof. Henry for using his magnetometer.** On June 2nd of 1842, Henry also described the way in which his magnetometer instrument in the laboratory was used to measure the magnitude (or equivalently, degree or intensity) of magnetization of a steel needle, and its polarity as follows:

> "I have mentioned that I had prepared[?] a new magnetometer, and since I have referred to it several times, yesterday, to day it will be best before going farther to describe the instrument. It is on the same principle as the instrument described [on] page [?left blank?]. The index needle is formed of a slender sewing needle 2 inches long, and balanced by a piece of wood at the larger end, (Thus see margin) and suspended by a fine silk filament in a paper stirrup[?]. The suspension string is at right angles to the plane of a graduated circle, and this is covered by a piece of mica cut out at one corner, so that the needle to be experimented on may [be] approached sufficiently near the end of the index needle. The sides of the figure are enclosed by glass. The oscillations of the needle are stopped by the glass plate, which is placed directly across the zero point. The repulsion of the needles drives the index from its point of rest, and the extreme dynamic deflection gives the magnetic force required. The for[c]e in this case is the *vis viva*. The operation of this instrument was very satisfactory."

---

[h] The usually wooden cover used to prevent leaves and debris from falling into the well.

In the field, Prof. Henry may have simply placed a magnetic compass near the magnetized needle. As per his June atmospheric experiment on dynamic induction from lightning, the needle point may have been stuck into a cork stopper and placed into a glass tube around which the coil wire could be formed. The coil wire could have been "commercial cork wire".

(c) Description of the receiver coil in the secondary circuit. In his first experiment on October 7th, he explicitly wrote [1 & 7] that he used

> ". . . the needle placed in the helix used in the study for atmospheric electricity"

Table 1.—Description of the Induction-at-a-Distance Experiments Performed on October 7, 1842 [1 and 7]

Experiment number: 1
Source: 3 jars of the French battery
Distance between 1^0 and 2^0 circuits: 60 feet between the closest parallel wires of the two circuits[i]
Descriptive remarks: "Two poles[j] supported by tripods formed of long slats of boards, were placed upright in the back campus". These poles supported a part of the 2^0 wire stretched over their tops and parallel to the 1^0 wire in Nassau Hall. This wire was continued backward on each side, until it extended to the two [Society] halls, it then crossed over with the two ends united, so as to form a "complete parallelogram". "A needle placed in a helix[k] connected with the secondary wire was strongly magnetized".

Experiment number: 2a
Source: A battery of 3 Leyden jars that were charged using his machine. A single discharge of the battery was made to the 1^0 wire that was grounded in a well.
Distance between 1^0 and 2^0 circuits: 90 feet between the closest parallel wires of the two circuits
Descriptive remarks: This experiment was repeated several times using a single needle each time. Did Henry use an intermediary calibration jar (i.e., his unit flask) of the Lane type to determine the quantity of charge? The "needles were magnetized to a degree scarcely less than" experiment 1.

- - -

Experiment number: 2b
Source: 1 jar, same wire arrangement as experiment 2a.
Distance between 1^0 and 2^0 circuits: 90 feet between the closest parallel wires of the two circuits
Descriptive remarks: The experiment was done once only, and the needle in the helix was "strongly magnetic".

Experiment number: 3
Source: "The jar was removed, and [using the machine] a single spark [was] thrown on to the suspended end of the conducting wire, while the other end was connected with the rubber".
Distance between 1^0 and 2^0 circuits: 90 feet between the closest parallel wires of the two circuits.
Descriptive remarks: Same wire arrangement as experiment 2b. "The needle with this [arrangement] was also magnetic but apparently not quite as strongly as before."

Experiment number: 4
Source: 3 jars gapped to the primary circuit
Distance between the 1^0 and 2^0 circuits: 165 feet between the 1^0 circuit wire in Nassau Hall and the parallel part of the 2^0 circuit wire "stretched between the two upper windows" above the doors closest to Nassau Hall of the entries of the "parallel colleges" (see diagram 1)
Descriptive remarks: The 2^0 "wire was removed from the long poles, and the parallel part stretched [across the breadth of the back campus] between the two upper windows" of the two parallel colleges that are over the entry doors closest to Nassau Hall.

---

[i] The terms 1^0 and 2^0 mean primary and secondary respectively.
[j] The height of the poles is not mentioned in Henry's surviving notes.
[k] Arago suggested the use of the wire helix for magnetization to Felix Savary in the 1820s. Savary was a Professor at the École Polytechnique in Paris, France. Henry had studied the researchers of Savary, and adopted the use of the magnetizing wire helix for his own subsequent experiments as a detector device for these electrical oscillating pulses.

from his studies on dynamic induction from lightning discharge. The coil that he used was described on June 10th. It was [1 & 7]

> "a compound spiral . . . [which] was formed of 6 strata [layers] of wire, each consisting of 45 spires [turns], and insulated by cement."

I interpret from an earlier reference in his laboratory notes of the point and eye of a needle, that he continued to use an ordinary steel sewing needle (American manufacturing specification size no. 5) in the same coil that he used as a detector in his atmospheric experiments of June 10, 1842, on dynamic induction from lightning. In fact, on Monday, May 16, 1842, Prof. Henry wrote that he used

> "a medium sized sewing needle"

for magnetization in a spiral that day. He also wrote about his use of a

> "slender sewing needle 2 inches long"

in his laboratory note of June 2, 1842, as reported above in section **2(b).** The helix and needle together comprised a detector for the signal. The degree and polarity of magnetization of the steel needle could be determined either roughly with a pocket compass, or with the magnetometer device that is described in section **2(b).**

3. Critique of the transmission experiments made on October 7th and 8th, 1842. There is no extant description of any insulation measures that may have been taken for the 400 foot length of copper wire through Nassau Hall, other than the description of using silk ribbon at the windows of all three buildings to support the wire and prevent it from being grounded by touching the masonry at the window locations.

In his June 10th, 1842 atmospheric experiments on lightning discharge, Henry stuck a needle into a cork stopper which he then placed into his vertically positioned helix. He used the compound spiral coil that is described above in section 2(c), which was interconnected into the grounded circuit of his June 10th lightning experiments. The wire coil (possibly of fine "commercial cork wire") could have been threaded around a glass tube (the wire loops being without question insulated by cement), in the manner he reported in his laboratory notes, and which is described above in section 2(c) of this paper. Henry inter-connected this coil into the secondary circuit in these experiments of October 7 and 8, of 1842.

In charging the flasks that he used in these experiments, Prof. Henry used a hand cranked grounded friction machine. In his method of charging the Leyden jar capacitor (i.e., condenser), he would count the sparks. The friction machine using a rubber is but one kind of electrostatic machine or generator. The other kind of electrostatic machine is the induction machine, such as the Holtz machine or the Wimshurst machine. A modern kind of electrostatic machine is the Van de Graaff generator. The Wimshurst machine might still be handily used today in certain applications.

The degree and polarity of magnetization of the steel needles used in these experiments would be tested at some time during or after the experiment on a magnetically responsive torsion balance device modelled after the Coulomb torsion balance device (See section **2b** above). He would note the direction of the turning of the recording needle of the torsion device (i.e., its direction (+ or −) and degree of deflection/torsion). The magnitude of the swing of the recording needle indicated the strength/intensity of the current. Another simple measure which was often adopted was to use the magnetic compass as Ørsted had done, with the compass held or laid near to a galvanic wire. The alternating current in these out-of-doors dynamic induction-at-a-distance experiments was transient. A travelling pulse of oscillations was sent along the primary wire.

Prof. Henry remarked that

> "The needles in all the above mentioned experiments [shown here as experiments 1, 2a, 2b, 3, & 4] were magnetized in the same direction . . ."

In experiments 5a and 5b, the forward parallel line of the secondary wire was moved farther away from Nassau Hall to the distance of 220 feet. It was stretched between the two upper windows of

> "the farther entry of the parallel buildings. . . . The needle placed in the helix [in the previous experiments] . . . was again magnetic, and in the same direction as in" [ref. 1; p. 8, & ref. 7; p. 100]

experiments 1, 2a, 2b, 3, and 4. Refer to diagram 1 for a depiction of the layout of the wire. This primary circuit had ground return through the dry soil consisting of compact shale, according to J. H. Lefroy, who in his letter of October 25, 1842 to Edward Sabine [8], stated that the distance of the helix in the secondary circuit (containing the needle to be magnetized) was set at about 600 feet. See also Lefroy's diary, page 173. There is no indication as to whether the helix was located in the forefront part or the rearward part of the parallelogram shaped wire circuit. There is no existing description here of the construction of any wooden support poles or any existing further information about insulation of the secondary wire circuit at this distance. Henry recorded that the weather on October 8, 1842, was damp, and that

> "In the morning a very heavy fog rested on the ground—until about 10 oclock AM." [ref. 1 and 7]

Table 2.—Description of the Induction-at-a-Distance Experiments Performed on October 8, 1842 (a Damp Day)

Experiment number: 5a
Source: 3 jars
Distance between 1^0 and 2^0 circuits: 220 feet = 165′ + 50′, which is the total distance between the 1^0 circuit wire in Nassau Hall and the parallel part of the 2^0 circuit wire.
Descriptive remarks: Secondary wire placed across the breadth of the back campus (i.e., the old campus behind Nassau Hall), at the distance from the farthest doors of the parallel colleges to Nassau Hall. The wire was supported at the windows above these entry doors, and was stretched between the two upper windows of "the farther entry of the parallel buildings". (See diagram 1).

- -

Experiment number: 5b
Source: 1 jar
Distance between 1^0 and 2^0 circuits: 220 feet
Descriptive remarks: Same as in experiment 5a: the needle was magnetized in the same direction as in the previous experiments, "but not to the same degree of intensity".

Experiment numbers: 6a, 6b, & 6c
Source: not known
Distance between 1^0 and 2^0 circuits: not known from Henry's surviving notes, although J. H. Lefroy (see Appendix III) mentioned a distance of about 600′. It could have been 300′[(1)].
Descriptive remarks: The secondary wire circuit is formed into a parallelogram, whose "farthest side was in the field beyond the society halls."[(2)] Therefore, the farthest side of the 2^0 circuit (i.e., the parallelogram of wire with the inter-connected small helical coil) is greater than 304′ from the 1^0 wire in Nassau Hall. Nothing was reported about insulation of the 2^0 circuit wire from the ground in experiments 6a, 6b, & 6c.

[1] J. Henry, London, Edinburgh & Dublin Phil. Magazine & Journal of Science, **30,** series 3 (1847) 186: Proc. American Philosophical Society, **iv**, p. 260: American Journal of Science, **3** (1847) 25.
[2] The Society hills evidently lie behind the two Society halls at the fartherest extension of the old back campus. The distance between the back of Nassau Hall facing the back campus, and the front of the two Society halls is 304 feet.

From the testimonies (Appendixes II and III) we infer two different setups for the primary wire. The first arrangement is earlier in time (1835 and 1836) and is powered by a direct current source. This could have been either a cruikshank or a daniell d.c. battery. Because Prof. Henry's laboratory notebook entry for May 12, 1840, noted that he used a daniell battery, and because of its electrical output characteristics, I am inclined to believe that he used this in his 1842 direct current test of the primary circuit. According to Lefroy's letter [8], the coil for the direct current test was introduced into the circuit in Prof. Henry's house, before exiting the line of wire towards the other well by his house. The purpose of this earlier 1835 and 1836 arrangement seems to be for the empowerment of an electromagnet to do work in causing a bell to ring for the purpose of communication. In this primary circuit, ground return closes the current between the two wells.

The 1842 primary circuit arrangement (in contradistinction to his 1835–6 setup) is mentioned in the testimonies (see both Appendixes) and is the one that is described by Henry [1 & 7] in his Laboratory notes of October of 1842, which carried a pulse of alternating current. In this setup, the primary wire is high above ground having passed to "the two upper ones [windows] of the East end of the old college [Nassau] hall" [1 & 7]. The primary wire arrangement is grounded at both ends in water wells. The primary wire passed through Prof. Henry's study in his house on the West side of the campus, exited through a window and was grounded in his water well. His electrostatic machine consisting of the prime conductor and rubber was located in his cabinet on the second floor of Philosophy Hall at the East side of the old front campus.

I can not determine from the remaining historical record of these experiments, how the rearwards portion of the parallelogram configuration of the secondary circuit was positioned so as to insulate it from the ground, if indeed it was. The primary circuit acted as a transmission line terminating in a characteristic impedance.

Experiments of October 1843

4. Description of the direct current tests on Monday, Oct. 16, in preparation of the circuits for the discharge to the primary and the induction of the secondary circuit wires. From what can be reconstructed from the description of the setup for Oct. 16, Prof. Henry stretched a line of copper bell wire across the breadth of the front campus from the second storey window of Philosophical Hall to the second storey window of his study in his home, the line then being continued out through another window to end at a water connection in the well situated next to his house for grounding. According to this reconstruction of these events, I envision that there was a sag in the 400 foot length of copper bell wire across the 315 foot wide campus, in front of Nassau Hall, which would resemble the appearance of wire hanging between telephone poles today.

Refer to Prof. Henry's remarks in Appendix IV, for his description of the arrangement of the primary and secondary wires, and for his method of testing, by which he was able to determine the poor conductivity of the soil between the two wells on the front campus.

The long length of copper bell wire was insulated at the windows by being overlain across the top of an insulating tube (supposed to have been made of

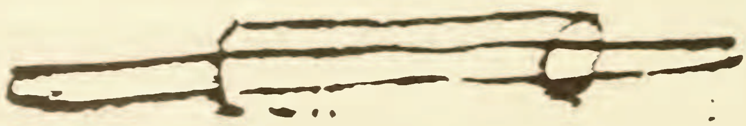


Fig. 1. Henry's own hand-drawn picture of his insulation technique of 1843

glass) which had been slipped over a round wooden stick emplaced horizontally into the frame of the window, as

"the stick was then fastened across the window" [1; vol III, pp. 70–76]

The end of the primary circuit wire in Philosophical Hall went to his "cabinet" where his batteries of one jar and of three jars, and his machine were kept. Another length of wire ran in turn, from there as grounding, out of the window

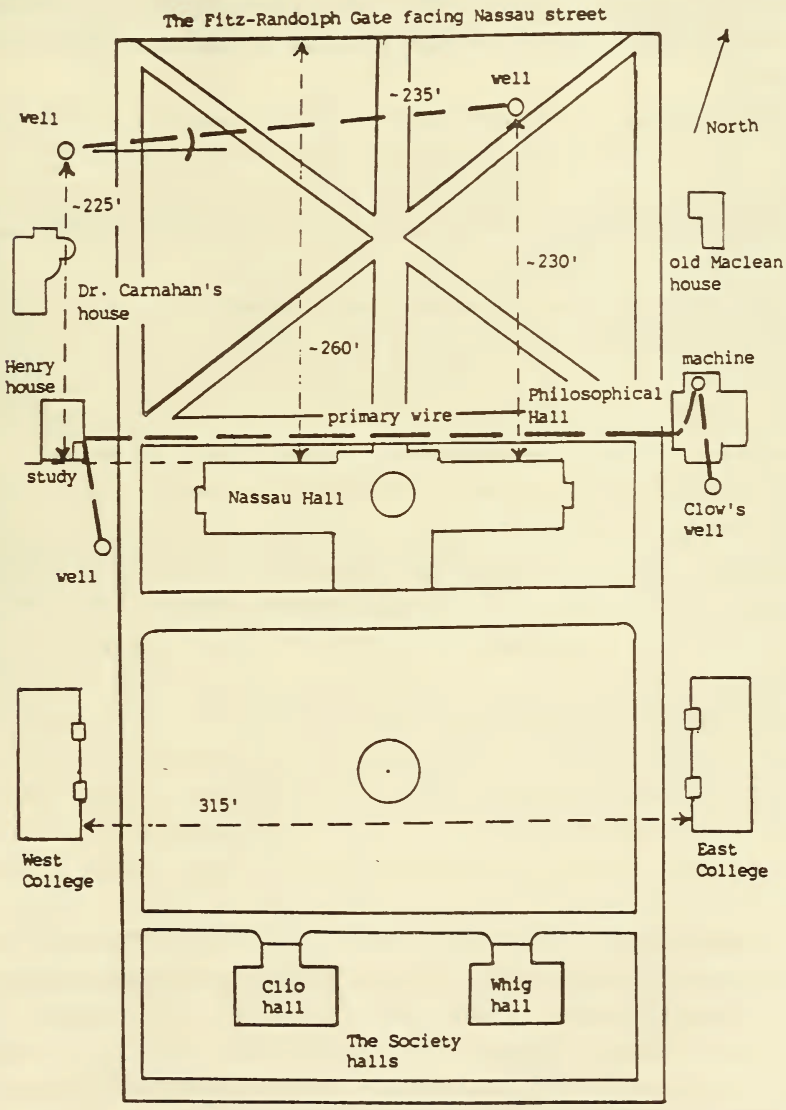


Diagram 2. Sketch of the campus of the College of New Jersey at Princeton, circa 1843, showing approximate locations of wiring

at the side of Philosophical Hall, ending in a water connection in Mr. Clow's well.

5. Discharge signal experiments performed in October 17 and 19, 1843. Two classes of discharge experiments were considered in this series of examinations, for the mutual field effects of a pair of very long wires across the breadth of the front campus at Princeton. The class of experiments done on Oct. 18, where the primary and secondary wires were about 18 inches apart, is of no concern for the purpose of this paper. In the other class of experiments that were conducted on October 17th and 19th, which is of concern to us, the secondary wire was far removed from the primary wire, and the layout of the wires is shown in diagram 2.

The following tests were made by Prof. Henry, whereby he determined the "adverse" nature of the current of the secondary circuit, the principal oscillation amplitude of the transient pulse being found to be of opposite sign (or in other words, of opposite polarity). The adverse nature was determined from the resulting polarity of magnetized needles after discharge.

The secondary line of wire lay between Maclean's well and Dr. Carnahan's well, and it was far apart (i.e., removed) from the parallel line of primary wire in front of Nassau Hall running from Philosophy Hall to Prof. Henry's study.

Chart 1 outlines the methodology of the class of test series of interest for the primary and secondary circuit wires far removed from each other.

6. On the possibility of ground return from the secondary wire. Prof. Henry excluded ground return currents as a possibility for explaining the observed magnetization effect at a distance from the source. The conductivity of the soil at Princeton is of the order of 10^{-3} siemen per meter (or in other words, 10E-03 siemen/m) and the conductivity of annealed standard copper wire at usual temperatures is about 5.8×10^7 siemens per meter; which is at least of ten powers of magnitude greater than the soil conductivity. If for example, experiment no. 1 is examined for its conductivity, it becomes immediately obvious that the recorded electromagnetic effect in the large loop of copper wire (i.e., the secondary wire circuit) will maintain the path of its current in the loop; and in no way, can an earth current be established from the loop to return to the primary wire.

7. The magnetization of the steel needles in the coil was caused by a transient alternating electric current in the secondary wire, and this current was induced by electromagnetic waves. Henry believed that the transmission in distance would increase with an increase in the length of his wires in the parallel wire arrangement. But it does not seem that he was concerned with the possibility of transmitting intelligent communication over distances, but rather with the inductive effects themselves, as regards polarity and intensity. Because ground

Chart 1.—Outline of the October 1843 Test Series

Date	Test no.	Remarks
Tuesday, Oct. 17	1	Deflections [n] of needles magnetized in coils (interconnected with the secondary wire), by a discharge from one Leyden jar. **SEE Table 2.** The spiral used in each discharge is identified by number or letter[o]).

Table 1.—One jar

Experiment group	a	1	2	3	4	Remarks
1	−22	−12.5	−17	−5	−3	highly charged
2	−20	−3	−15	−3	−1	
3	−20	−10	−18	−3	−1	
4A	−45	−45	−40	−20	−4	
4B		−45	−38	−23	−2	stronger charge—loud snap
5A	−25	−12	−18	−4	−0	
5B		−17	−12	−3	−0	

RESULT. "all the [above] results give an induced current opposite to that of the [discharging] battery" [1].

Date	Test no.	Remarks
Tuesday, Oct. 17	2	Deflections [n] of needles magnetized in coils [o] (interconnected with the secondary wire), by a discharge from two Leyden jars. SEE **Table 1.**

Table 2.—Two jars

Experiment group	a	1	2	3	4
1	−20	−3	−7	−11	−0
2	−20	−20	−3	−12	−2

[n] These deflections were measured in relative units of measure.
[o] J. Henry designated by the letter a, the coil he used in his lightning discharge experiments of June 2, 1842, and his inducation at a distance experiments of October 1842.

Date	Test no.	Remarks
Tuesday, Oct. 17	3	Tests performed using a coil of about 300 turns of wire, attached into the secondary wire, with a needle suspended in the center. A movement of the needle occurred when the alternating current transient was passed from the discharge of a Leyden jar. With three jars, the movement of the needle was greater. Reversal of the discharge still indicated a current adverse to the discharge current of the primary circuit.

RESULT. Movement of the needle occurred when the a.c. was passed from the discharge of a Leyden jar. With 3 jars, the movement of the needle was greater. Reversal of the discharge still indicated a current adverse to the discharge current of the primary circuit.

NOTE. Some other experiments were performed on October 17th; and Prof. Henry also mentioned that he used Dr. Franklin's battery of 24 jars with a charge of 100 units. The weather had become more damp.

Date	Test no.	Remarks
Thursday, Oct. 19	4	The "adverse" effect of the discharge current was also determined by means of a method that was due to C. Matteucci (Annals de chimie 1847).

return currents can be ruled out, the question naturally arises as to whether Prof. Henry was observing an effect that was due to magnetic induction or an effect that was due to the creation and detection of electromagnetic waves. A crude means by which a decision can be attempted as to whether the observed magnetization effect was due to the presence of electromagnetic waves, is to model the primary wire as straight and parallel to and situated at a sufficient height above the ground, and calculate an approximate value for the frequency, and see if this value is in the range of radio spectra. Therefore, given

The parameters describing the primary circuit wire

length ℓ	= 400 feet	= 12,192 cm
diameter d	= 0.05 inch	= 0.127 cm
height h	= 19 feet	= 579.12 cm

and using the appropriate formulas [9] for estimation of capacity C for a single wire parallel to the ground, (for which by algebraic reduction, I derived a simpler version of formula 117 on page 237 of Ref. 9), and for the estimation of inductance L for a fine copper wire,

$$C = 0.2416\ell \div [\log_{10}(4h/d) + \log_{10} A];$$

$$A = (\ell + \sqrt{\ell^2 + d^2}) \div (\ell + \sqrt{\ell^2 + 16h^2})$$

$$L = 0.002\ell[2.303 \log_{10}(4\ell/d) - 0.75]$$

and the formulas for frequency $f = 1/2\pi\sqrt{LC}$ and wavelength $\lambda = cf^{-1}$ (where c = 2.997×10^8 meters per second, is the velocity of the propagation of light in air according to A. A. Michelson), the following can be shown:

Comparative estimations of electromagnetic parameters for a primary wire of a 400 foot (121.92 m) length

$C \approx 691.92 \times 10^{-12}$ farads
$L \approx 295.31 \times 10^{-6}$ hernies
$f \approx 3.52 \times 10^5$ cycles/sec or Hz
$\lambda \approx 850.8$ meters/cycle

The magnetization of the steel needle in every experiment was caused by the induction of a transient alternating electric current in the secondary wire. The record of the October 1843 experiments shows that the negative polarity of the magnetization of the steel needle is a remnant that corresponds to the positive polarity of the initial electric current alternation in the primary wire. The initial alternation of current possessed the greatest amplitude in this ringing of the circuits.

The steel needle and the coil surrounding it, together constitute the detector of the transient field of the wave at time approximately r/c (r being the approximate distance between the two circuits) after transmittal of the wave from the primary wire, since the primary and secondary circuit elements are not infinitesimal in size. A train of waves in these experiments, corresponded to a single spark. The activating of a train of waves and current oscillations is called ringing the circuit. From the standpoint of human cognition, the intellectual recognition of the existence of this magnetization event may be considered to be the signal. From a physical standpoint however, the signal may be considered to be the actual physical event itself. The detected wave was wireless.

Acknowledgements

I wish to thank Prof. Hugo F. Sonnenschein, Provost of Princeton University, and Mr. Eugene J. McPartland of the Office of the Vice President for Facilities at Princeton University, for their assistance in procuring various measurements of the buildings and distances on the grounds of the old campus. I also thank Dr. Marc Rothenberg, editor of **The Papers of Joseph Henry** for coaxing me with gentle humor to strengthen my concluding remarks.

References

1. **Joseph Henry**, experiment on Oct. 8th, 1842, *Laboratory Notebook*, Volume III, Box 21, Record of Exp[eriments], 1834–1862; Papers: Research and Lectures, Smithsonian Archives, Washington, D.C.
2. **Proceedings of the American Philosophical Society.** Vol. II. August, Sept. & Oct., 1842. No. 23, page 229. "Stated Meeting, Oct. 21. Present, thirty-nine members".
3. *Smithsonian Report* for 1865, page 18.
4. **A Memorial of Joseph Henry,** Smithsonian Institution, Government Printing Office, 1880, published by order of Congress (L. C. call no. Q143.H6 S7):
   i. William B. Taylor, page 306;
   ii. Henry Clay Cameron, page 174;
   iii. Joseph Henry in a letter to Rev. S. B. Dod, from the City of Washington, December 4, 1876. Refer to Roman numeral I on page 150;
   iv. Henry Clay Cameron, page 172;
   v. William B. Taylor, page 243;
   vi. Joseph Henry in a letter to Rev. S. B. Dod, from Washington, D. C., December 4, 1876. Refer to Roman numeral IV on pp. 151–152;
   vii. S. B. Dod, "Discourse, by Rev. S. B. Dod", page 143.
5. **Ernest B. Rutherford,** "Magnetization of Iron by High-frequency Discharges", Trans. of the New Zealand Institute, vol. 27 (1894) pp. 481–513. See also *The Collected Papers of Lord Rutherford of Nelson,* vol. 1, pp. 25–57, Interscience Publishers Inc., New York 1962 (L.C. QC3.R93).
6. **E. B. Rutherford,** "A Magnetic Detector of Electrical Waves and some of its Applications", Philosophical Transactions of the Royal Society, 1897, ser. A, vol. 189, pp. 1–24 (Received June 11—Read June 18, 1896). See also The Collected Papers of Lord Rutherford of Nelson, pp. 80–104.
7. **Albert G. Gluckman,** *Selected Passages on Magnetic Induction and inductive Phenomena, taken from the Laboratory Notes of Joseph Henry,* Research Notes and Memoranda of Applied Geometry for Prevenient Natural Philosophy, POST-RAAG Reports, Extra Number 12 (January 1986) Libr. Congress no. Q1.R45 Extra no. 12 and QC 754.2.M33. Refer also to the Science Museum at South Kensington, London, UK.
   The source of these notes is found in the Archives of the Smithsonian Institution in Record Unit 7001, Joseph Henry Collection, 1808, 1825–1878, and related papers to circa 1903, Box 21, Volumes 1 and 2.

8. **Sabine Papers,** Records of Kew Observatory, Public Record Office, London: Sabine Papers, section BJ3/35, Transcripts of Crown-copyright records in the Public Record Office.
(a) See also: The Papers of Joseph Henry, vol. 5, October 25, 1842. pp. 281–287, Smithsonian Institution, City of Washington. Refer especially to pp. 283–284. (L.C. no. Q143.H52A1).
9. **Radio Instruments and Measurements,** National Bureau of Standards circular C74, Edition of 1924 reprinted in 1937 (L.C. call no. TK6550.U58).

Appendix I

Suggestion Made by Faraday in 1846 for Explaining the Action of Radiant Phenomena Including Gravitation, by Transverse Vibrations of Lines of Force Instead of an Aether

In his Note, Faraday hypothesized that

> "a notion which as far as it is admitted, will dispense with the aether. . . . The consideration of matter under this view gradually led me to look at the lines of force as being perhaps the seat of the vibrations of radiant phenomena."
>
> . . .
>
> "The power of electric conduction (being a transmission of force equal in velocity to that of light) appears to be tied up in and dependent upon the properties of the matter, and is, as it were, existent in them."
>
> . . .
>
> "Whatever the view adopted respecting them may be, we can, at all events, affect these lines of force in a manner which may be conceived as partaking of the nature of a shake or lateral vibration."
>
> . . .
>
> "It may be asked, what lines of force are there in nature which are fitted to convey such an action and supply for the vibrating theory the place of the aether? I do not pretend [t]o answer this question with any confidence; all I can say is, that I do not perceive in any part of space, whether (to use the common phrase) vacant or filled with matter, anything but forces and the lines in which they are exerted. The lines of weight or gravitating force are, certainly, extensive enough to answer in this respect any demand made upon them by radiant phenomena. . . ."
>
> . . .
>
> "The view which I am so bold as to put forth considers, therefore, radiation as a high species of vibration in the lines of force which are known to connect particles and also masses of matter together. It endeavours to dismiss the aether, but not the vibration."

Appendix II

Testimonies Concerning Placement of Primary Circuit Wire in 1835 and 1836

These testimonies in Appendix II concern that setup arrangement of the primary circuit in the earlier years (1835 and 1836), it being different from the setup arrangement (or placement) of the primary circuit wire in the experiments in 1842.

The end attachments of the primary circuit wire were located in each well. This circuit wire seems to have gone from the window of the upper story of the library building, down to what seem to have been insulating supports located on the grounds of the "front campus" facing (i.e., in front of) Nassau Hall; and then across the breadth of the front campus at about ground level, and up into a window in Philosophical Hall, thence out a window, and then down into the second well for grounding. Refer to diagrams 1 and 2 above, and to the pictures drawn by Henry in his *Laboratory Notebook* [1] on page 6, of the date Oct. 6, 1842, for an illustration of the setup of his primary circuit.

Prof. Henry [4.iii] gave the following description of the setup for his primary wire arrangement in a letter that he wrote to the Reverend S. B. Dod, on December 4, 1876.

> "I think the first actual line of telegraph using the earth as a conductor was made in the beginning of 1836. A wire was extended across the front campus of the college grounds, from the upper story of the library building to the philosophical hall on the opposite side, the ends terminating in two wells. Through this wire, signals were sent, from time to time, from my house to my laboratory."

Another description of the setup of Prof. Henry's primary wire arrangement was given by Prof. Henry Clay Cameron [4.iv]

> "From his lecture-room to the opposite building, and thence to his house, which was the house now occupied by General Kargé, but then standing on the site of Re-Union Hall, stretched a wire, through which currents of electricity were sent that rang bells and thus conveyed messages."

William B. Taylor [4.v]:

> "In 1835, wires had been extended across the front campus of the college grounds at Princeton from the upper story of the library building to the Philosophical Hall on the opposite side, through which signals were occasionally sent, distinguished by the number of taps of the electro-magnetic bell. . . ."

Appendix III

Testimonies Concerning the Placement of the Primary Circuit Wire in 1842

In the experiments of October 1842, the primary circuit wire extended through the second story of Nassau Hall, elevated high above the ground.

A description of the primary wire arrangement used in the series of 1842 experiments is found in a letter from the English military officer John Henry Lefroy to Edward Sabine [9].

> "He [Henry] leads a wire 400 ft from his Physical Cabinet [Laboratory room] to his house, where it joins an helix, and is conducted into a well. At the other end he forms a dimutive battery of about halfinch plates, also communicating

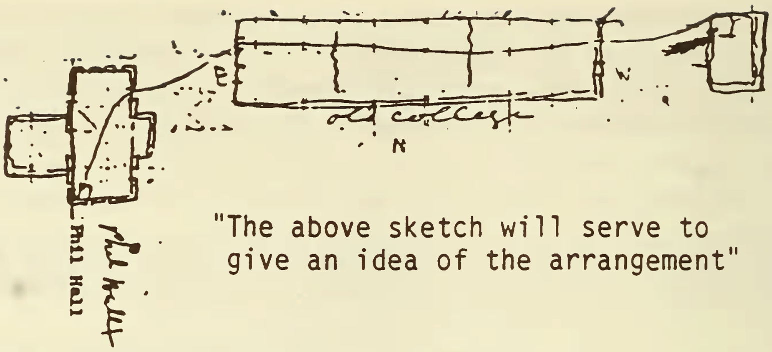


Fig. 2. Henry's own hand-drawn picture of his primary wire layout of October 1842

with another well there. In ⟨*making*⟩ immersing the plates a ⟨*circuit*⟩ current is transmitted which magnetizes the needles in the helix, the circuit being completed only through the *dry soil* (compact shale) between the two wells[p]. He finds that *every machine*[q] spark he makes in his cabinet [laboratory room], magnetizes a needle in an helix formed in a wire entirely unconnected with the machine, or the building, and about 600 ft distant."[r]

The following account appears in to **The Papers of Joseph Henry** [8a].

"For Henry's account of the meeting with Lefroy, see Record of Experiments, October 15, 1842, above. The experiment Lefroy described is in the Record of Experiments entries of October 6, 7, and 8, 1842, above. Henry and

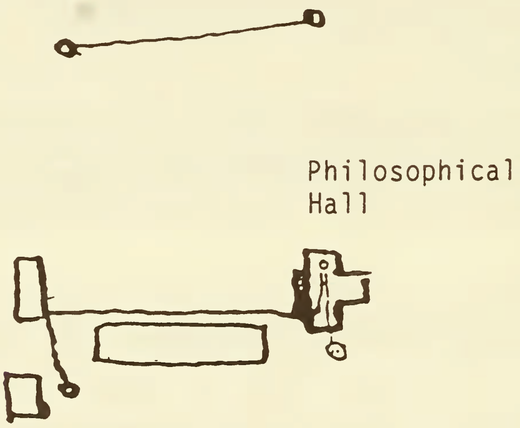


Fig. 3. Henry's own hand-drawn picture of his primary and secondary wire layout of October 1843 on the old front campus

[p] This description is the same as found in Prof. Henry's description of the preliminary test on the primary circuit that was made on the morning of October 6, 1842. The well by Dr. Carnahan's house was about 7.5 feet across, and the well by the Maclean house was about 6.25 feet across.

[q] The electrostatic friction machine with the grounded leather "rubber".

[r] Also refer to Lefroy's **Diary**, page 173.

> Lefroy took their magnetic measurements in 'Mr. Clow's Field,' two hundred yards [editor] southwest of the college (Lefroy, diary, p. 173), the same field in which Henry's electrical experiment was set up."

Appendix IV

Monday, October 16, 1843. The Experimental Setup

According to Prof. Henry, on the afternoon of Monday, October 16, 1843, he

> "Arranged . . . a wire across the campus[s] for transmitting a discharge of electricity from[t] + the Phil[osophical] Hall to the well opposite our house[u] [after having entered/ingressed and exited/egressed], and back through the ground to Mr[.] Clow's well at the end of Phil. Hall." [1; vol. III, pp. 70–76]

Monday, October 16, 1843. The Testing of the Earth Connections of the Primary and Secondary Circuits with Direct Currents

Prof. Henry

> "tested by means of the galvanometer with the[?] small single battery, the negative element of which was formed of a silver thimble, and the positive of a single point of zinc plate. . . . When the circuit[?] was completed, the needle was violently agitated by[?] the mere touching of the point of zinc to the surface of the acid".

---

[s] This line of wire was "stretched across the campus [breadth] in front of Nassau Hall", according to Henry.

[t] In the old Franklin single fluid theory, + indicates the excess of electricity; that is, the terminal of Henry's primary wire was at the indicated source of charge.

[u] After having entered and egressed via the windows at the upper storeys of the two buildings, in accordance with the remarks made by Prof. Henry [4.iii] in his letter to S. B. Dod of December 4, 1876, and Prof. Clay Cameron's remarks [4.iv], in which there were described the layout of the primary wire for Prof. Henry's earlier experiments in 1836, according to Henry.