The Electrical Discoveries of JOSEPH HENRY

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AN historical research into the accomplishments of a great scientist, such as Henry, includes two main parts. There is first the proof, based upon the record, that he accomplished certain things. This being an affirmative proof can be quite definite. There is a second step, however, which is of interest in the appraisal of his work, namely, showing in respect to what items he was first. This means in effect proving that in respect to these items no one anticipated him. Such an assertion, being a universal negative, cannot be absolutely proved, but can, of course, by sufficient work be shown to be probable in a high degree.

The student of Joseph Henry's work is hampered in the number of items which can be included in the affirmative proof by the fact that no adequate record has been preserved. Henry was slow and fragmentary in publication and most of his personal records were destroyed in a fire at the Smithsonian Institution in 1865. While his publications and the testimony of others who saw his experiments show a prodigious accomplishment, it is probable that a more complete record would have added other important contributions made by Henry to electrical science, and in other fields of scientific work.

When one attempts to appraise Henry's work in comparison with that of his contempories, and particularly to determine in what cases Henry's discoveries were prior to those of others, the difficulty is multiplied. There was a complete lack of means for rapid communication one hundred years ago. As a result scattered scientists working in the same field often independently made similar discoveries and the scientific journals in which their results were published were neither rapidly nor widely distributed. The result is illustrated by the fact that so fundamental an advance as Ohm's law, published in full in 1827, was little known or accepted even in Europe for a decade.

The original notes of the scientific investigators are for the most part, with the outstanding exception of Michael Faraday, not available, and credit for priority of discovery has generally, by common consent, been associated with priority of publication. Even at the time there were some interesting cases in Europe where conflicting claims of priority were made and the implication is made in some cases that the scientific accuracy even of the scientists themselves is open to question where matters of priority are concerned. As stated by Arago,

"Those who discover a new fact in the sciences of observation must expect, first, to have its correctness denied,—next its importance and utility contested,—and afterwards will come the chapter of priority,—then, passages, obscure, insignificant, and previously unnoticed, will be brought forward in crowds as affording evident proofs of the discovery not being new." [1]

One hundred years later the determination of questions of priority is still difficult and it is small wonder the different writers on the subject of Joseph Henry's electrical discoveries have not always been in complete agreement as to the items for which priority should be assigned to Henry. In an attempt to resolve these uncertainties a study has been made of the published accounts of the more important discoveries of Joseph Henry in the electrical field and of the work of his contemporaries in that field. Reference has been made to the original of the publications cited by earlier investigators to indicate priority or lack of priority for Henry's work.

The results of this study are given below. It is naturally not a complete review of this complicated situation, relating as it does only to selected items of Henry's electrical work and, furthermore, other references may be found which affect the conclusions reached. It is believed, however, that this study is a contribution towards a more exact appraisal of Joseph Henry's work, and if it is of assistance to others who may in the future wish to carry this review still further, it will doubly have served a useful purpose.

In the selection of material for this review it is the intention to include in it the discoveries of Joseph Henry which are the more important from the standpoint of subsequent practical applications of electricity. The following summary indicates briefly what these discoveries were, and the conclusions in each case resulting from this study. The somewhat voluminous reference material on which the conclusions are based is given in the appendix to this paper, arranged under the same numbered headings as the summary.

Summary of Henry's Discoveries Included in This Study

1. Construction of Electromagnets (1829 and 1830)

Henry used insulated wire for the winding of electromagnets instead of the single spiral of non-insulated wire which had previously been used, and devised windings with more than one layer. By this means he was able to increase very greatly the strength of electromagnets and to make them practicable for general use. His form of construc-

[1] *Meteorological Essays* by Francois Arago, London, 1855, p. 291.

tion is universal for electromagnets today. Insulated wire had previously been applied to other uses, including galvanometer coils, but not to magnets.

2. Proportioning of Magnet and Battery for Maximum Effect (1830)

Henry pointed out that the coils of the magnets constructed by his method could be made up either of one very long wire or several shorter ones, showed the proper relative proportioning of magnet and battery for maximum effect in these two cases and pointed out that the intensity magnet and battery were suitable for operating over line wires of considerable resistance, while the quantity magnet and battery were suitable for local circuits. This result was arrived at experimentally before Henry had any knowledge of Ohm's law, and is the first recognition of the necessity for properly proportioning the impedance of different parts of an electric circuit which has become an important quantitative requirement in the design of all forms of electric circuit, particularly in communication circuits.

3. Electromagnetic Motor (1831)

Henry was the first to publish a description of an electric motor using electromagnets and a commutator. This motor was a reciprocating device, therefore quite different in form from the commercial motors developed later. It did, however, contribute these two fundamental elements of permanent value and also served to rouse interest in and stimulate work on the problem of obtaining mechanical power from electricity.

The question has been raised whether Henry was not anticipated by Salvatore dal Negro of Padua, who made a similar motor apparently in the same year. While the evidence on this point is somewhat circumstantial, it seems to indicate clearly that Henry was first in publication. It is probable that dal Negro's work was done without knowledge of Henry's, but there is no evidence to indicate that his motor was constructed earlier than Henry's.

4. Telegraphy (1831 and 1832)

By the application of his principles of proper proportioning of magnet winding, battery and external circuit resistance, Henry produced the first telegraph using electromagnets as a receiving device. The idea of using galvanic current for telegraphy at a distance had previously been investigated by Barlow and later the control of electromagnets at a distance by transmitting current over a line wire was investigated by Wheatstone without knowledge of Henry's work done five years earlier. In both cases the project was rejected as impracticable because of their lack of appreciation of this principle of proper proportioning.

Henry's telegraph included an "intensity" battery, a line wire of more than one mile in length and a receiving device consisting of an electromagnet with polarized armature so arranged as to strike a bell when reversals of current were sent. The use of the electromagnet made rapid signaling possible and has formed the basis of practically all subsequent commercial telegraph development. He was also the first to employ audible reception, which has played a very important part, particularly in American telegraph practice.

In Henry's later telegraph experiments he used a grounded circuit which has played a very important part in telegraph development. Grounded circuits had, however, been used before Henry in experiments with electric telegraphs of other types.

In 1850 in a Morse patent suit a claim was made that in 1830 Abraham Booth from Dublin had demonstrated a similar electromagnetic telegraph. A search of important contemporary publications, however, reveals no evidence to support this claim.

5. *Electromagnetic Induction (1832)*

Faraday and Henry both independently discovered the phenomena of mutual induction and of self induction. On the basis of date of publication the discovery of mutual induction is properly credited to Faraday (1831, published 1832) and the discovery of self induction to Henry (1832). The determination of this question is recognized in the official adoption by the International Electrical Congress of 1893 of the name "henry" for the practical unit of inductance.

It is interesting to note that in 1804 Vassali-Eandi observed that the shock obtained in opening a long circuit was greater than that received by merely touching the battery terminals. While this fact was due to the self inductance of a circuit this observation did not constitute an anticipation of Henry, as no thought of induction, either self or mutual, was in the mind of the investigator. Also, in connection with his investigations of mutual induction in 1831, Faraday conceived that conductors might have the property of self inductance, and carried on experiments designed to detect this property. His experiments, however, showed a negative result.

6. *Electromagnetic Relay (1835)*

Henry first discovered and demonstrated the principle of the electromagnetic relay. The relay was used by him at the end of his telegraph line to open the local circuit of a large magnet and to demonstrate the possibility of producing a great mechanical effect at a distance. This invention is, of course, fundamental to the operation of electrical systems of all kinds: telephone, telegraph and electric power.

7. Non-Inductive Winding (1835)

Both Henry and Faraday devised non-inductive windings in connection with their experiments on self induction. Henry's publication was, however, slightly earlier than Faraday's. The non-inductive windings so described are fundamentally the same in principle as those now used for resistance coils and other apparatus where self inductance is reduced to a minimum.

It is interesting to note that before the discovery of self induction Faraday constructed for use in certain experiments on mutual induction an apparatus closely parallel to the non-inductive winding, namely, two closely associated secondary windings connected in series opposing.

8. Transformer (1838)

While both Faraday and Henry used a transformer structure in their first mutual induction experiments, it was only later (1838, published 1839) that it was discovered by Henry that by the proper proportioning of the coils the voltage could be stepped up or stepped down with this structure. This is fundamentally the basis of modern electrical transformers.

9. Electromagnetic Shielding (1838)

Henry discovered the screening effect of all good conducting substances interposed between two coils, i.e. the primary and secondary of a transformer. After publishing his results Henry learned of Faraday's results published at about the same time purporting to show that this screening effect did not exist except with magnetic materials. Henry thereupon explained the reason for this apparent discrepancy and reaffirmed his own results.

He also pointed out that this principle has an important bearing on the improvement of electrical machinery, and explained the advantage which had been found by using bundles of wires instead of solid pieces of iron, i.e. lamination.

10. Discoveries Bearing Particularly on Radio Telegraphy and Telephony (1838 to 1842)

Henry (1838, published 1839) showed the variation in current induced in a secondary circuit as the separation between primary and secondary is varied. This is the principle of the variometer widely used in radio work.

Henry then (1842) carried his investigations to considerable distances, producing high frequency oscillating currents in a primary circuit by the discharge of a battery of Leyden jars, and detecting the result in secondary circuits at a distance first of 30 feet and then of several hundred feet. He concluded that every spark of electricity in motion exerts inductive effects at distances indefinitely great and likened the propagation of this effect to the propagation of light which he surmised was merely another kind of wave in the same medium. It is an extraordinary fact that in these experiments Henry had what would now be considered a form of radio transmitter and receiver, and that he believed the results to be produced by an electromagnetic radiation comparable with light. This was 25 years before the work of Maxwell and more than 40 years before the work of Hertz.

Henry is sometimes credited with having discovered the oscillatory nature of the discharge of the Leyden jar (1842). Felix Savary, however, in 1827 had advanced the hypothesis that this discharge is oscillatory in order to explain his experimental results. Henry repeated Savary's investigations and brought about the acceptance of Savary's hypothesis as a result of his authoritative affirmation that this hypothesis was correct.

The above record of the achievements of Joseph Henry, partial though it be, is the more impressive in consideration of the difficulties under which Joseph Henry labored. He worked in a frontier country far from the current of European scientific thought and with only occasional information regarding the results achieved by others. Furthermore, in his early years his work was limited largely to summer vacations, his time being fully occupied by teaching during the school year. His financial limitations were serious. His results were achieved by great industry in the application of his genius for practical experimentation, his inventive insight, his power for exact observation and his sense of perspective and proportion.

APPENDIX

References Bearing on Henry's Electrical Discoveries

1. *Construction of Electromagnets*

a. Use of Insulated Wire

Insulated wire was used before Henry's work for various purposes including electrostatic telegraphs and galvanometers. For example, the wire of the coil in Schweigger's galvanometer as made by Oersted was:

". . . wrapped or wound round throughout its whole length, in silk thread. Thus all electric communication is avoided between the different parts of this wire, the turns of which are wound one over or above the other, as it is placed in the groove of the frame." [2]

Insulated wire had not been applied to magnets, they being constructed by insulating the magnet core and winding on it a single spiral of uninsulated wire. The following is Henry's first description of the application of insulated wire to magnets:

"In a paper, published in the *Transactions of the Albany Institute*, June, 1828, I described some modifications of apparatus, intended to supply this deficiency of Mr. Sturgeon [weak magnetic effects], by introducing the spiral coil on the principle of the galvanic multiplier of Prof. Schweigger, and this I think is applicable in every case where strong magnets cannot be used. . . . Shortly after the publication mentioned, several other applications of the coil, besides those described in that paper, were made in order to increase the size of electro-magnetic apparatus, and to diminish the necessary galvanic power. The most interesting of these, was its application to a development of magnetism in soft iron, much more extensively, than to my knowledge had been previously effected by a small galvanic element.

"A round piece of iron, about 1/4 of an inch in diameter, was bent into the usual form of a horse-shoe, and instead of loosely coiling around it a few feet of wire, as is usually described, it was tightly wound with 35 feet of wire, covered with silk, so as to form about 400 turns; . . . ." [3]

The nearest approach which has been found to a contemporary statement indicating possible anticipation by others is the following published by Silliman in his journal for July, 1837:

"Prof. Moll, of Utrecht, by winding insulated wire around soft iron, imparted to it prodigious magnetic power, so that a horse shoe bar, thus provided, and connected with a galvanic battery, would lift over one hundred pounds. About the same time, Mr. Joseph Henry, of Albany, now Prof. Henry, of Princeton College, by a new method of winding the wire, obtained an almost incredible magnetic force. . . ."

However, reference to Moll's own account of his work published in the *Edinburgh Journal of Science* April-October, 1830, and copied in *Silliman's Journal* for January, 1831, and to another contemporary account of Moll's work gives no indication of his having used insulated wire.

Henry also used other insulating materials. In SW, Vol. 1, p. 48 (1831), he acknowledged Dr. Beck's suggestion for using well waxed cotton instead of silk thread and also mentioned Dr. Beck's experiments with iron bonnet wire "which, being found in commerce already wound, might possibly be substituted in place of copper. . . ."

In 1832 he described winding the armature of a magnet with "A piece of copper wire, about thirty feet long and covered with elastic varnish. . . ." [4] In this, however, he was anticipated as to publication

[2] *Electro-Magnetism etc.*, Jacob Green, 1827, pp. 81–83.
[3] SW,* Vol. 1, pp. 37–38; paper published January, 1831.
[4] SW, Vol. 1 p. 75.

* *Scientific Writings of Joseph Henry*, published by the Smithsonian Institution in 1886.

at least by Professor Hare of the University of Pennsylvania, who in a letter of February 24, 1831, published in *Silliman's Journal* of July 1831, stated with reference to wire for magnets, "I used no wrapping, but merely shell lac varnish, applied in winding. . . ." The same issue of *Silliman's Journal* quotes a letter from Professor J. W. Webster of Harvard of February 7, 1831, stating, "In constructing the magnetic apparatus, there is considerable economy in using sealing wax instead of silk."

b. Multiple Layer Windings

In 1831 Henry wrote as follows:

"At the same time [1829 or 1830], a very material improvement in the formation of the coil suggested itself to me, on reading a more detailed account of Prof. Schweigger's galvanometer, and which was also tested with complete success upon the same horse-shoe; 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 that the galvanic current might circulate in the same direction in both. . . ."[5]

This is generally acknowledged to be the first publication of the use of this important improvement in magnet construction.

In Henry's early work the windings were wound directly on the magnet core. It is not clear whether he later wound up coils separately intended to be applied to the magnet cores after winding. This form of construction, however, was used by Professor Hare as early as 1831 in making the Henry type magnets. In a letter of March 4, 1831, he described in detail the process of winding the coil on a mandril and later slipping it over the core, apparently as an improvement in construction detail.[6]

2. *Proportioning of Magnet and Battery for Maximum Effect*

Henry, in a paper published January, 1831, described a series of experiments instituted jointly with Dr. Philip Ten Eyck for the purpose of determining how the type of magnet and battery and the length of the interconnecting wires affected the magnetic force produced. From the results he concluded that:

"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."[7]

3. *Electromagnetic Motor*

In 1821 Faraday made the first electric motor, the action of which was the rotation of a current-carrying wire around the pole of a perma-

[5] SW, Vol. 1, p. 39.
[6] *Silliman's Journal*, July, 1831.
[7] SW, Vol. 1, p. 42.

nent magnet. This was followed by Barlow's motor in which a spur-shaped wheel, with current flowing through it radially, rotated between the poles of a permanent horse-shoe magnet. Henry, in an undated letter published in *Silliman's Journal* in July, 1831,[8] described in detail and illustrated an electro-magnetic rocker arm machine, provided with a commutator. This letter commences with the following statement:

"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 its 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 question is sometimes raised whether Henry's motor was not anticipated by a similar one made by Salvatore dal Negro of Padua. A review of the original publications of dal Negro, while indicating that he independently invented a motor similar to Henry's, seems to indicate clearly that his dates of publication were later. The facts are these:

The first brief description of dal Negro's motor is given in a memoir entitled, "New Electro-magnetic Experiments and Observations," published in *Nuovi Saggi della Imperiale Regia Accademia di Scienze Lettere ed Arti in Padova*, Volume III, 1831. This volume is a collection of papers covering the years 1825–31, inclusive, and is one of a series of volumes issued at irregular intervals of 3 to 8 years, apparently for the purpose of providing a permanent record. This volume includes the statement that the dal Negro paper was presented before the Academy of Padua on June 21 and July 10, 1831. There is no indication how much later than this the volume was published, although the character of the volume and the other evidence in this case suggest that it may well have been published at the end of 1831 or later.

In this memoir, parts 1 to 3 inclusive, comprising 16 pages and a plate of illustrative figures, describe batteries and magnets. Part 4, only one page in length, with no figures, describes the motor very briefly as follows:

"*Part 4—A New Electro-magnetic Motor*

Having succeeded in building temporary magnets capable of holding up considerable weights by means of electromotors [batteries] of very moderate size and therefore of very small cost, I have engaged myself in the study of the way of employing this new force towards setting in motion a machine of any sort, and now I am about to

[8] SW, Vol. 1, p. 54.

outline briefly to you, illustrious members of the Academy, the various manners which I have devised for putting a lever into motion.

1. The first lever I have set in motion consists of a magnetized steel bar, set vertically between the ends of a temporary magnet. The bar oscillates in response to succeeding magnetic attractions and repulsions which take place between the S pole of the bar and the S and N poles of the temporary magnet, which poles are continually reversed by the same lever. By means of the same contrivance the lever can be made to oscillate in a horizontal plane.

2. . . . ."

The rest of part 4 deals in a general way with other methods of producing motion by the use of electro-magnets and is not of interest in this discussion.

A bi-monthly publication entitled *Annali delle Scienze del Regno Lombardo—Veneto, Padova,* in its issue of July–August 1831, gives a review of the presentation of the dal Negro paper before the Academy of Padua. This review, which is more than a thousand words long, covers very completely the subject matter of the first three parts of dal Negro's paper. It makes no mention whatever of the new electro-magnetic motor. Since the description of the motor appears to be the most novel and interesting part of the paper as finally published, the omission of any mention of it in the published review naturally raises a question whether the description of the motor was a part of the paper as originally presented.

Furthermore, in the November–December 1831 issue of *Annali delle Scienze* the first three parts of dal Negro's paper are published, but not the fourth part. In this there is no reference to the electro-magnetic motor except the following statement in the introductory part, given as one of the reasons for presenting the paper:

"4. Finally, because I hope to have enriched physics with a new motor, having succeeded in putting into motion in various manners a lever, taking advantage of the strength of temporary magnets."

The article is marked "to be continued," which suggests that it was the intention to add in a later issue a description of the electro-magnetic motor mentioned in the introduction. However, a review of subsequent issues fails to reveal any publication of part 4.

The above evidence indicates that the brief description of dal Negro's motor mentioned above probably was not published before the end of 1831, and raises considerable doubt whether it was included in the original draft of dal Negro's paper presented before the Academy in June and July, particularly in view of the lack of any mention of this part of the paper in the very full report of the meeting published in August.

The first full description of dal Negro's machine was published in the *Annali delle Scienze* for March and April 1834. This paper includes the following footnote:

" This new instrument was made by me in the year 1831 and I have already mentioned this in the fourth part of my first memoir on temporary magnetism which I published in volume VI of the *Atti dell' Accademia di Scienze, Lettere ed Arti di Padova*." [The volume number appears to be an inaccurate reference to volume III of *Nuovi Saggi*, etc. as indicated above.]

4. *Telegraphy*

In 1831, following the description of the experiments which led to his discovery of the proper proportioning of the battery and the magnet, Henry stated:

"But be this as it may, the fact, that the magnetic action of a current from 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 electro-magnetic telegraph. . . ." [9]

Henry later corrected this reference to Barlow since Barlow's investigation merely tended to disprove the possibility of the telegraph. Barlow's statement regarding the telegraph was:

" In a very early stage of electro-magnetic experiments, it had been suggested, that an instantaneous telegraph might be established by means of conducting wires and compasses. The details of this contrivance are so obvious, and the principles on which it is founded so well understood, that there was only one question which could render the result doubtful, and this was, Is there any diminution of effect by lengthening the conducting wire? . . . I was, therefore, induced to make the trial, but I found such a sensible diminution with only 200 feet of wire, as at once to convince me of the impracticability of the scheme." [10]

Even as late as 1837, Wheatstone in England had satisfied himself by experiment that the development of electro-magnetism in soft iron at a distance was impracticable. Cooke had sought to develop magnetism at a distance for the purpose of sounding an alarm. His experiments were unsatisfactory and on asking advice of Faraday and Roget was referred by the latter to Wheatstone. Wheatstone's statement was:

"I believe, but am not quite sure, that it was on the 1st of March 1837, that Mr. Cooke introduced himself to me. . . . Mr. Cooke [later] showed me some of his drawings and models, and though I could not fully comprehend the full scope of them at the time, I saw and understood enough to assure me that his instrument was a massive complicated piece of machinery, intended to be set in action by the attractive power of an electro-magnet. On seeing this, and relying on my former experience, I at once told Mr. Cooke that it would not and could not act as a telegraph, because sufficient attractive power could not be imparted to an electro-magnet interposed in a long circuit; and to convince him of the truth of this assertion, I invited him to King's College, to see the repetition of the experiments on which my conclusion was founded. He came, and after seeing a variety of voltaic magnets, which even with powerful batteries exhibited only slight adhesive attraction, he expressed his disappointment in these words, which I well remember, 'Here is two years' labour wasted.'" [11]

Henry in 1831 or 1832 at Albany acted on his own suggestion as to

[9] SW. Vol. 1, p. 42.
[10] *Edinburgh Philosophical Journal*, Jan.–Apr. 1825.
[11] *The Electric Telegraph: Was It Invented by Professor Wheatstone?*, by W. F. Cooke, Part 2, pp. 86–87.

the applicability of his discovery to the electro-magnetic telegraph At that time he published no description of his experiments, but did so a number of years later. There are also accounts of several eye-witnesses to them, the following from a letter of James Hall to Henry, January 19, 1856.

"While a student of the Rensselaer School, in Troy, New York, in August, 1832, I visited Albany with a friend, having a letter of introduction to you from Professor Eaton. Our principal object was to see your electro-magnetic apparatus, of which we had heard much, and at the same time the library and collections of the Albany Institute.

"You showed us your laboratory in a lower story or basement of the building, and in a larger room in an upper story some electric and galvanic apparatus, with various philosophical instruments. In this room, and extending around the same, was a circuit of wire stretched along the wall, and at one termination of this, in the recess of a window, a bell was fixed, while the other extremity was connected with a galvanic apparatus.

"You showed us the manner in which the bell could be made to ring by a current of electricity, transmitted through this wire, and you remarked that this method might be adopted for giving signals, by the ringing of a bell at the distance of many miles from the point of its connexion with the galvanic apparatus." [12]

And Dr. Orlando Meads, a former student of the Albany Academy, in 1863 in a discourse commemorating an anniversary of the Academy, thus referred to the scenes he had witnessed one-third of a century before:

"The older students of the Academy in the years 1830, 1831, and 1832, and others who witnessed his experiments which at that time excited so much interest in this city, will remember the long coils of wire which ran circuit upon circuit for more than a mile in length around one of the upper rooms in the Academy, for the purpose of illustrating the fact that a galvanic current could be transmitted through its whole length so as to excite a magnet at the farther end of the line, and thus move a steel bar which struck a bell." [13]

Henry had two applications of his electro-magnets in mind: first, the production of a machine to be moved by electro-magnetism and, second, the transmission of or calling into action power at a distance.

". . . for the purpose of experimenting in regard to the second, 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." [14]

Henry later used the grounded circuit, another close parallel to the form taken in the practical development of the telegraph. This principle, however, had been used years earlier in electrostatic telegraphs and in firing gun powder at a distance, e.g., by Cavallo in 1794–5 and Salva in 1798.[15]

[12] *Annual Report Smithsonian Institution* 1857, p. 96.
[13] *A Memorial of Joseph Henry*, published by Order of Congress, 1880, p. 380.
[14] SW, Vol. 2, p. 434, 1857.
[15] *A History of Electric Telegraphy to the Year 1837*, by J. J. Fahie, 1884, pp. 99 and 108.

In the case of Smith vs. Downing, a telegraph infringement suit tried at Boston in 1850, a witness, Oliver Byrne by name, made the following statement.

"In the year 1830, I attended the public lectures of Abraham Booth (afterward scientific reporter for the *Times* newspaper, and who became Dr. Booth), delivered in Dublin, among other subjects, on electricity and electro-magnetism. In said lectures, the said Booth, in my presence, used in combination a long circuit of insulated wire conductors, or galvanic battery, an electro-magnet with an armature and mercury cups to join and disjoin the circuit, with which he magnetized and demagnetized the iron of the electro-magnet, causing it to attract the armature when the circuit was joined, and to recede from it when disjoined. Mr. Booth, at that time, stated to his audiences that that power could be produced and used at distant places, as signs of information; and he repeatedly illustrated what he meant, by causing the armature to approach the magnet, and then to fall from it on the floor, stating at the same time that it made marks by so falling." [16]

A search was made of various indices and publications, including *The Royal Society Catalogue of Scientific Papers*, 1800–1863; *Transactions of Royal Irish Academy*, 1786–1886; *Royal Dublin Society Catalogue*, 1731–1839, by J. F. Jones; *British Museum Catalogue;* Glazebrook's *Dictionary of Applied Physics;* J. J. Fahie's *History of the Telegraph*, previously referred to; and William B. Taylor's *An Historical Sketch of Henry's Contribution to the Electro-Magnetic Telegraph*, 1879. No further report or particulars of Abraham Booth's work, aside from the same quotation in Fahie's book, was found to support the statement and it is not therefore considered to constitute adequate evidence of anticipation of Henry.

5. *Electromagnetic Induction*

Henry's first description of his experiments on self-induction is included in his paper in *Silliman's Journal* of July, 1832. After describing experiments on mutual induction he proceeded with the following:

"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." [17]

[16] *Historical Sketch of the Electric Telegraph*, by Alexander Jones, 1852, p. 32.
[17] SW, Vol. 1, p. 79.

Faraday's first communication on self-induction, in the *Philosophical Magazine* of November, 1834, does not state the matter very clearly. A more detailed paper read before the Royal Society on January 29, 1835, clearly presents the matter, including the following quotation:

"The case, therefore, of the bright spark and shock on disjunction may now be stated thus: If a current be established in a wire, and another wire, forming a complete circuit, be placed parallel to the first, at the moment the current in the first is stopped it induces a current in the *same* direction in the second, the first exhibiting then but a feeble spark; but if the second wire be away, disjunction of the first wire induces a current in itself in the same direction, producing a strong spark. The strong spark in the single long wire or helix, at the moment of disjunction, is therefore the equivalent of the current which would be produced in a neighbouring wire if such second current were permitted." [18]

It is interesting to note that Faraday ascribed the momentary character of the induced current in a secondary conductor to the development in that conductor of an "electro-tonic" state, which tended to oppose the flow of current. The following interesting statement is made in a paper read on November 24, 1831:

"The current of electricity which induces the electro-tonic state in a neighbouring wire, probably induces that state also in its own wire; for when by a current in one wire a collateral wire is made electro-tonic, the latter state is not rendered any way incompatible or interfering with a current of electricity passing through it (62). If, therefore, the current were sent through the second wire instead of the first, it does not seem probable that its inducing action upon the second would be less, but on the contrary more, because the distance between the agent and the matter acted upon would be very greatly diminished." [19]

Faraday then quoted experiments on an electrical conductor designed to detect "a return current . . . due to the discharge of its supposed electro-tonic state." These experiments were, however, unsuccessful. In view of the failure of the experiments, these speculations are not considered to constitute an anticipation of the discovery of self-induction made by both Henry and Faraday at a later date.

Another reference which is of interest regarding early observations of self-induction is the following published in the *Philosophical Magazine* in 1804 under the heading "Intelligence and Miscellaneous Articles."

"*Velocity of the Galvanic Fluid*

"Vassali-Eandi has lately made some experiments on this subject, as Beccaria did in regard to the velocity of the electric fluid. The fluid of a pile of twenty-five pairs of plates traversed in a second thirteen metres (forty-two feet and a half) of gold cord. In another experiment with a pile of fifty pairs, the fluid passed along a copper wire plated with silver, three hundred and fifty-four metres (1151 feet) in length, in a time incommensurable: the shock in this case was three times as strong as that experienced by immediately touching the two extremities of the pile." [20]

[18] *Experimental Researches in Electricity* by Michael Faraday, Volume 1, paragraph 1092.

[19] *Experimental Researches*, Volume 1, paragraph 74.

[20] Volume 18, p. 374.

It appears that the experimenter observed the phenomenon of momentary high voltage produced by the "extra current" later observed by Henry, but that it was in no sense an anticipation of the discovery of self-induction since it was not so interpreted, no thought of induction, self or mutual, being in the mind of the experimenter.

Henry's first publication on mutual induction was in *Silliman's Journal*, July, 1832. He mentioned having seen a short account of Faraday's work and the method he used, saying:

> "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." [21]

He then described his experiment, which consisted in opening and closing the circuit of an electro-magnet and noting the effect on a galvanometer connected to a coil wound around the armature of the magnet.

Faraday read a detailed paper November 24, 1831, on mutual induction, this appearing in *Philosophical Transactions*, 1832. The account Henry saw was the proceedings of the Royal Institution as reported in the *Philosophical Magazine* for April 1832, as follows:

> "Feb. 17.—Mr. Faraday gave an account of the first two parts of his recent researches in electricity; namely, volta-electric induction, and magneto-electric 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 current produced, by induction, in B, in the opposite direction. . . . 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. . . . 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. . . . Thus is obtained the result so long sought after,—the conversion of magnetism into electricity." [22]

6. *Electromagnetic Relay*

The date of Henry's first electro-magnetic relay is generally given as 1835. It was made at Princeton (where he went towards the end of 1832) after he became settled in his duties there, and before he went to England in 1837. Edward N. Dickerson,[23] a Princeton student in 1839, said that Henry put his relay in operation at Princeton in 1835. Henry's earliest description of the relay, from a deposition of 1849, is as follows:

> "In February, 1837, I went to Europe; and early in April of that year Prof. Wheatstone, of London, in the course of a visit to him in King's College, London, with Prof. Bache, now of the Coast Survey, explained to us his plans of an electro-magnetic telegraph; and, among other things, exhibited to us his method of bringing

[21] SW, Vol. 1, p. 75.
[22] *Philosophical Magazine*, April, 1832, pp. 300–301.
[23] *Joseph Henry and the Magnetic Telegraph: An Address by Edward N. Dickerson, LL.D.*, 1885.

into action a second galvanic circuit. . . . I informed him that I had devised another method of producing effects somewhat similar. This consisted in opening the circuit of my large quantity magnet at Princeton, when loaded with many hundred pounds weight, by attracting upward a small piece of moveable wire, with a small intensity magnet, connected with a long wire circuit. When the circuit of the large battery was thus broken by an action from a distance, the weights would fall, and great mechanical effect could thus be produced, such as the ringing of church bells at a distance of a hundred miles or more, an illustration which I had previously given to my class at Princeton. . . . The object of Prof. Wheatstone, as I understood it, in bringing into action a second circuit, was to provide a remedy for the diminution of force in a long circuit. My object, in the process described by me, was to bring into operation a large quantity magnet, connected with a quantity battery in a local circuit, by means of a small intensity magnet, and an intensity battery at a distance." [24]

Under date of March 16, 1857, Henry transmitted to the Board of Regents of the Smithsonian Institution a "statement in relation to the history of the electro-magnetic telegraph" for the investigation of their special committee. Referring in his letter to his 1849 deposition he stated:

"My testimony was given with the statement that I was not a willing witness, and that I labored under the disadvantage of not having access to my notes and papers, which were in Washington. The testimony, however, I now reaffirm to be true in every essential particular." [25]

As a result of its investigations the Committee reported as follows:

"We have shown . . . that Mr. Henry's deposition of 1849 . . . is strictly correct in all the historical details, and that, so far as it relates to Mr. Henry's own claim as a discoverer, it is within what he might have claimed with entire justice. . . ." [26]

7. *Non-Inductive Winding*

The earliest reference to the use of the non-inductive winding by Henry was in a verbal communication made by him January 16, 1835, before the American Philosophical Society, a report on which was published March, 1835. He described it in more detail in a paper read February 6, 1835, as follows:

"One of these ribbons was next doubled into two equal strands, and then rolled into a double spiral with the point of doubling at the centre. By this arrangement the electricity, in passing through the spiral, would move in opposite directions in each contiguous spire, and it was supposed that in this case the opposite actions which might be produced would neutralize each other. The result was in accordance with the anticipation; the double spiral gave no spark whatever, while the other ribbon coiled into a single spiral produced as before a loud snap. Lest the effect might be due to some accidental touching of the different spires, the double spiral was covered with an additional coating of silk, and also the other ribbon was coiled in the same manner; the effect with both was the same." [27]

Faraday, in his paper read before the Royal Society January 29,

[24] *Annual Report of Smithsonian Institution*, 1857, pp. 111–112.
[25] *Annual Report of Smithsonian Institution* 1857, p. 87.
[26] *Annual Report of Smithsonian Institution* 1857, p. 98.
[27] SW, Vol. 1, p. 94.

1835, and published in the Philosophical Transactions of that year, described the non-inductive winding as follows:

"Thus, if a long wire be doubled, so that the current in the two halves shall have opposite actions, it ought not to give a sensible spark at the moment of disjunction: and this proved to be the case, for a wire forty feet long, covered with silk, being doubled and tied closely together to within four inches of the extremities, when used in that state, gave scarcely a perceptible spark; . . . ." [28]

Prior to this discovery Faraday in 1832 had constructed for use in certain experiments on mutual induction an apparatus closely parallel to the non-inductive winding, namely, two secondary windings twisted about each other to associate them as closely as possible and then wound in the form of a helix. With these windings connected in series opposing, he found no mutual inductive effect.[29]

8. *Transformer*

In Henry's article, "On Electro-Dynamic Induction," read November 2, 1838, and published the following year, after referring to Faraday's discovery of mutual induction he stated:

"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." [30]

The experiments bearing on the transformer he partially summarized as follows:

"This experiment was considered of so much importance, that it was varied and repeated many times, but always with the same result; it therefore establishes the fact *that an 'intensity' current can induce one of 'quantity,'* and, by the preceding experiments, the converse has also been shown, that *a 'quantity' current can induce one of 'intensity.'*" [31]

9. *Electromagnetic Shielding*

Both Henry and Faraday made extensive experiments of the effect of non-magnetic shields on induction between primary and secondary coils. That the important screening effect was observed by Henry seems to have been due to his method of observation which indicated instantaneous or peak voltages, in contrast to Faraday's which gave only a measure of the total quantity of induced electric displacement.

Prior to his work on electro-magnetic shielding, Henry knew of the discovery of magnetic rotation by Arago and of the various experiments by Herschel, Babbage and Harris. These experiments had shown that a revolving magnet gives rotation to metallic discs or needles suspended

[28] *Experimental Researches in Electricity* by Michael Faraday, Vol. 1, paragraph 1096.
[29] *Experimental Researches*, Vol. 1, paragraph 194.
[30] SW, Vol. 1, p. 114.
[31] SW, Vol. 1, p. 118.

above it and that this action is stopped by an interposed screen of magnetic material or thick plates of copper, silver, or zinc. Also, Faraday had shown that the rotation is due to inductive rather than magnetic action, the rotating magnet causing induced currents in the suspended body.

Henry did not know of the experiments on screening which Faraday had made and which were the subject of a paper read June 21, 1838, and published in the *Philosophical Transactions* for that year.[32] In this work Faraday found that a copper plate interposed between a primary and a secondary coil had no effect on the induction as indicated by a galvanometer, apparently of the slow-period type. Under this condition of measuring, the induced currents in the shields, which set up a flux opposing that of the primary coil, die out before the galvanometer response is well under way, so that the deflection is dependent only on the total change of flux in the secondary coil and hence substantially independent of the screen.

Henry, on the other hand, using shocks, which are indicative of instantaneous or peak voltages, as the measure of induction, observed the important principle of shielding, namely, that an interposed nonmagnetic metallic conducting screen prevents sudden changes of flux through the screen. The "measuring instrument" in this case being instantaneous, the opposing effect of the currents induced in the shield is observed. Henry communicated these results to the American Philosophical Society November 2, 1838, a report of which, published in 1839, stated that a part of the paper:

> "relates to the effect of interposing different substances between the conductor which transmits the current from the battery, and that which is arranged to receive the induced current. All good conducting substances are found to screen the inducing action, and this screening effect is shown, by the detail of a variety of experiments, to be the result of the neutralizing action of a current induced in the interposed body."[33]

Henry, on later learning of Faraday's results and of the then apparent discrepancy between those and his own, investigated the subject further with additional experiments, and from the experimental data and theoretical reasoning arrived at a fair reconciliation of the various observations.[34]

Speaking of the phenomena of circulating currents induced in an interposed shield, Henry said:

> "Also the same principle appears to have an important bearing on the improvement of the magneto-electrical machine: since the plates of metal which sometimes form the ends of the spool containing the wire, must necessarily diminish the action,

[32] *Experimental Researches in Electricity* by Michael Faraday, Vol. 1, paragraphs 1709–1736.
[33] SW, Vol. 1, p. 106.
[34] SW, Vol. 1, pp. 169–188.

and also from experiment of paragraph 72 the armature itself may circulate a closed current which will interfere with the intensity of the induction in the surrounding wire. I am inclined to believe that the increased effect observed by Sturgeon and Calland, when a bundle of wire is substituted for a solid piece of iron, is at least in part due to the interruption of these currents. I hope to resume this part of the subject, in connection with several other points, in another communication to the Society." [35]

At the end of the meeting in which this communication was presented, Dr. Bache gave an account of investigations of Professor Ettingshausen of Vienna, in which he had been led to suspect the development of a current in the metal of the keeper of the magneto-electrical machine, which diminished the effect of the current in the coil about the keeper. Mentioning this communication, Henry said:

"It gives me pleasure to learn that the improvements, which I have merely suggested as deductions from the principles of the interference of induced currents (76), should be in accordance with the experimental conclusions of the above named philosopher." [36]

Under date of November 13, 1838, a few days after Henry's communication to the American Philosophical Society, a communication bearing on this subject was sent to *Silliman's Journal* by Charles G. Page and published in that *Journal* in January, 1839. Mr. Page states:

". . . I would not say that a very careful insulation [of the iron wires forming a magnet core] might not improve their operation. For I apprehend that in the development and return of magnetic forces, electrical currents are excited in the body of the magnet at right angles to its axis, as well as in the wires surrounding the magnet."

The work of Foucault, whose name is often associated with this type of induced current, was published in *Comptes Rendus*, 1855. Foucault was familiar with the work of Arago and Faraday, but did not mention the work of Henry.

10. *Discoveries Bearing Particularly on Radio Telegraphy and Telephony*

a. *Variation of Induction Between Coils with Separation*

Henry, in his extensive investigations of induction, as presented in a paper in 1838 and published in 1839,[37] showed that the current induced in the secondary of two helical coils could be varied or regulated by changing the relation in space of the coils. The following from several of Henry's applications of this principle gives a partial summary of the results of his investigations:

"The action at a distance affords a simple method of graduating the intensity of the shock in the case of its application to medical purposes. The helix may be sus-

[35] SW, Vol. 1, p. 126.
[36] SW, Vol. 1, p. 145.
[37] SW, Vol. 1, pp. 119–122.

pended by a string passing over a pulley, and then gradually lowered down towards the plane of the coil, until the shocks are of the required intensity." [38]

b. Action of Induction at a Distance

Henry investigated the action of the discharge of a Leyden jar through a primary circuit in inducing currents in distant secondary circuits. For example, the following report of a paper read in 1842 was published the following year:

". . . a single spark . . . thrown on the end of a circuit of wire in an upper room, produced an induction sufficiently powerful to magnetize needles in a parallel circuit of wire placed in the cellar beneath, at a perpendicular distance of thirty feet with two floors and ceilings . . . intervening. . . . . . . when it is considered that the magnetism of the needle is the result of the difference of two actions, it may be further inferred that the diffusion of motion in this case is almost comparable with that of a spark from a flint and steel in the case of light." [39]

These experiments were carried to greater distances as is illustrated by the following excerpt from the proceedings of the meeting of the American Philosophical Society, October 21, 1842:

"Prof. Henry communicated, orally, an extension of the experiments, which he had previously brought before the Society, on electro-dynamic induction. He 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." [40]

Also, in the notes on "Lectures on Natural Philosophy by Professor Henry" made by William J. Gibson, a student, February 28, 1844, after a description of experiments on induction at a distance in which inductive effects were noted several hundred feet away, it is stated:

"Hence the conclusion that every spark of electricity in motion exerts these inductive effects at distances indefinitely great (effects *apparent* at distances of one-half a mile or more); and another ground for the supposition that electricity pervades all space. Each spark sent off from the Electrical Machine in the College Hall sensibly affects the surrounding electricity through the whole village. A fact no more improbable than that light from a candle (probably merely another kind of wave or vibration of the same medium), should produce a sensible effect on the eye at the same distance." [41]

This is also referred to in Henry's letter to Rev. S. B. Dod, written in 1876 as follows:

"As another illustration of this, it may be mentioned that when a discharge of a battery of several Leyden jars was sent through the wire before mentioned, stretched across the campus in front of Nassau Hall, an inductive effect was produced in a parallel wire, the ends of which terminated in the plates of metal in the ground in the back campus, at a distance of several hundred feet from the primary current, the building of Nassau Hall intervening. The effect produced consisted in the magnetization of steel needles." [42]

[38] SW, Vol. 1, p. 121.
[39] SW, Vol. 1, p. 203.
[40] *Proceedings of the American Philosophical Society*, Vol. 2, Jan., 1841–May, 1843.
[41] Manuscript in Princeton Library, p. 135.
[42] *A Memorial of Joseph Henry*, published by order of Congress, 1880, pp. 151–152.

The effect of lightning on an electroscope had been observed prior to Henry's work. In extending this work, Henry connected a wire to the metallic roof of his study, carried this wire through a magnetizing spiral and to ground, by means of which arrangement needles were magnetized in his study "even when the flash is at a distance of seven or eight miles, and when the thunder is scarcely audible." [43] William J. Gibson, in 1844, in his notes on Henry's lectures, states that needles were magnetized by lightning 20 miles away.

c. Oscillatory Nature of Discharge of Leyden Jar

Anomalies in the polarity of small steel needles magnetized by the discharge from the Leyden jar had been observed prior to Henry's work notably by Felix Savary, who in 1827 advanced in the following words the hypothesis that these results were due to the oscillatory discharge of the Leyden jar:

> "An electric discharge is a phenomenon of movement. Is this movement a continuous translation of matter in a determined direction? Then the opposite polarity of magnetism observed at different distances from a straight conductor, or in a helix with gradually increasing discharges, would be due entirely to the mutual reactions of the magnetic particles in the steel needles. The manner in which the action of a wire changes with its length appears to me to exclude this supposition.
>
> "Is the electric movement during the discharge, on the other hand, a series of oscillations transmitted from the wire to the surrounding medium and soon attenuated by resistances which increase rapidly with the absolute velocity of the moving particles?
>
> "All the phenomena lead to this hypothesis which makes not only the intensity but the polarity of the magnetism depend on the laws in accordance with which the small movements die out in the wire in the surrounding medium and in the substance which receives and conserves the magnetism." [44]

Henry repeated and extended Savary's investigations and confirmed Savary's hypothesis by a clear and authoritative statement of the phenomenon 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, and a ready explanation is afforded by it of a number of phenomena which are to be found in the older works on electricity, but which have until this time remained unexplained." [45]

References

For convenience there is given below a list of the principal publications referred to in connection with the study as original sources. Many of the references cover the general field of electrical discovery contemporary with Henry; others relate to specific items of the work.

[43] SW, Vol. 1, p. 203—Paper presented in 1842 and published the following year.
[44] *Annales de Chimie et de Physique*, 1827.
[45] SW, Vol. 1, p. 201, 1842.

A number of these references are mentioned in the discussion of specific items. The list does not include thirty or forty present day publications relating to Henry's work, which were reviewed, from many of which valuable suggestions were obtained as to where to look for source material, but which were not themselves used as sources.

Scientific Writings of Joseph Henry, published by the Smithsonian Institution, 1886.
Experimental Researches in Electricity, by Michael Faraday, D.C.L., F.R.S., 1839.
A Memorial of Joseph Henry, published by Order of Congress, 1880.
Annual Report of the Smithsonian Institution for 1857.
Students' Notes on Henry's Princeton Lectures, MSS. in Princeton Library.
The Electric Telegraph: Was It Invented by Professor Wheatstone?, by William Fothergill Cooke, London, 1857.
Historical Sketch of the Electric Telegraph, by Alexander Jones, New York, 1852.
A History of Electric Telegraphy to the Year 1837, by J. J. Fahie, London, 1884.
An Historical Sketch of Henry's Contribution to the Electro-Magnetic Telegraph, by William B. Taylor, 1879.
Joseph Henry and the Magnetic Telegraph: An Address, by Edward N. Dickerson, LL.D., 1885.
The Annals of Electricity, Magnetism, etc., by William Sturgeon, 1836–1843, London.
Scientific Memoirs, Edited by Richard Taylor, F.S.A., London, 1837–1852.
Electro-Magnetism, etc., by Jacob Green, M.D., Philadelphia, 1827.
Meteorological Essays by Francois Arago, London, 1855.
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Nuovi Saggi della Imperiale Regia Accademia di Scienze Lettere ed Arti, in Padova, Vols. I–VI, 1817–1847.
American Journal of Science (Silliman's Journal), 1822 and 1827–1842.
Proceedings of American Philosophical Society, Vols. 1–3, and Vol. for 1744–1838.
Transactions of American Philosophical Society, Vols. VI–VIII (1834–1842).
Philosophical Transactions, London, 1831, 1832, 1834, 1835, and 1838.
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