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The Discovery of Oscillatory Electric Current

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ABSTRACT

The history of the discovery of electric oscillation is reviewed.

I. Introduction

After Oersted's discovery in 1820, of a magnetic influence from a galvanic circuit, the two separate phenomena of electricity and of magnetism were tied together to form the new science of electromagnetism. The next evolutionary advance taken, was the discovery in 1826 by Felix Savary of Paris, of oscillatory currents produced by a discharge. His discovery was reasoned from experimental observation of the magnetic periodicity of fine steel needles, when they became magnetized as a consequence of the discharge current of the Leyden jar.

During the period of years from 1835 until 1842, Joseph Henry of the College of New Jersey at Princeton (later to become Princeton University) developed his theories on the nature of the discharge current. For the purposes of this paper, only those of his discharge studies that were concerned with his conceptualization of the phenomenon of electric oscillation are considered. Prof. Henry's 1842 experiments concerning the oscillatory nature of the discharge current, were completed with his knowledge of the previous work of Savary, whom he mentions. But Henry's experiments were masterpieces of applications of self-made equipment, not only to prove the existence of oscillatory currents discharging from the Leyden jar, but also to show the existence of oscillatory currents for various induction at a distance setups, as well as for what he called "dynamic induction" at a distance from lightning.

Karl Wilhelm Knochenhauer postulated a theory in 1842, for the existence

of electric oscillations in an electrically stressed aether impregnating what we now call the dielectric medium of the condenser (i.e., capacitor). This electrical stressing of the aether in the glass, was a consequence, he thought, of the charging of the Leyden jar. In 1847, Hermann Ludwig Ferdinand Helmholtz derived the oscillation of electric discharge currents from the principle of the conservation of energy.

2. Studies by Felix Savary on Magnetic Periodicity, and His Subsequent Deduction of the Existence of Oscillatory Current

Discharge currents produced in the early 19th century, were those from the Leyden jar, or the magic tableau (tablet) which is also known as the Franklin square. This is a device consisting of a sheet of glass dielectric that is sandwiched in between two sheets of foil, and this may also have been called a battery. Another source for a discharge current was the cascade or succession of sparks that were thrown from the prime conductor of a hand cranked friction machine. The 18th century version of this machine uses a belt to obtain a high rate of rotation, generally of a glass disk or glass sphere that is held against a leather "rubber". This type of machine was invented by Francis Hawksbee in 1709. Today, such a machine would be called an electrostatic generator or an electron pump. Later 19th century machines of this type include the Holtz and the Wimshurst generators. Other than this, the magneto-electric generator was in use, such as the Saxton machine invented by the American Joseph Saxton of Philadelphia and London, or the Pixii machine.

I begin with the discharge studies of Felix Savary (born in 1797 and died in 1841) who was Professor of Astronomy and Geodesy at the École Polytechnique of Paris. What then was the intellectual source for Prof. Savary's investigation of the magnetism that is developed from the discharge circuit, and how was he led to the distinction between a discharge current and a voltaic current whose source was the pile of Volta? He and de Monferrand (called Demonferrand by James Cumming[1] of the same period, who was President of the Cambridge Philosophical Society and professor of chemistry at Cambridge University; see ref. 2) had published a study to demonstrate Coulomb's laws of force for electric currents in closed voltaic circuits, and a new application of the formula of Ampère to represent the mutual action of two infinitely small portions of the electric current. Self-induction and mutual induction were but an evolutionary step removed from the study of the mutual actions of the magnetism of one or two circuits. Because this study by Savary and de Monferrand is a side issue in this history, it is not placed in the reference section, and for those readers who find such things of interest, it suffices to

say that their study was read at the Academy of Sciences meeting of 3 February 1823, and published in vol. 22 (1823) pp. 259–264, of the Bibliothèque universelle (LC: Q2.A77).

But these studies by Savary and de Monferrand answer only a part of the question regarding the intellectual source of Savary's inquiry into the nature of the discharge current. The other part of the question seems to be answerable from Savary's comments about a new series of experiments that were carried out by Leopoldo Nobili (born in 1784 and died in Florence in August of 1835). According to the remarks translated from French[16] in Savary's paper:

> [pages 8–9]
> "Since the researches of Mr. Arago, Mr. Nobili has published on some interesting magnetization experiments. One of these consists in making an examination, of either the electric discharge, or the current of the pile (Mr. Nobili has never separated these two means of magnetization), with a plane spiral of copper wire. If between the spires [which are] insulated one from the other[,] one fixes, perpendicularly to its plane, some needles of steel, one finds that the needles situated towards the center and adjacent to the circumference are magnetized in contrary senses; [and] that by consequence at a certain distance from the center the magnetization is null."

We can recognize a number of ideas from this paragraph. Firstly, note that Nobili at that time failed to distinguish between the current of the discharge (which today we recognize as a.c.) and the current of the pile (which today we recognize as d.c.). Secondly, and this is most important, Savary saw in Nobili's experiment, the contrary senses of magnetism imparted to the steel needle depending upon its position with regard to the center of the spiral and the circumference of the spiral; implying that the magnetism of a needle can change polarity depending upon where it is situated in distance at various positions on the wire spiral. This idea can be regarded as the most important source of these investigations by Savary which led him to his discovery of the oscillatory nature of the discharge current.

Consider now, his experiments. They are summarized in Table I.

Nobili's above-mentioned study of the influence of the position of the needle fixed perpendicularly to the flat coil, on the polarity of magnetism after the discharge current has passed, I believe, is the germinal ideal in Savary's research on oscillatory current. The following question and reply were made by Savary.[16] The reply is a statement of his theory which came from his experiments.

> [pages 54–56]
> "is the movement of electricity during the discharge, composed, to the contrary, of a suite of oscillations, transmitted from the wire to the surrounding medium, and soon amortisized by the resistances which increase rapidly with the absolute velocity of the agitated particles?"

Table 1.—Experiments reported by F. Savary in his 1827 paper

1. Rectilinear wire experiments (using different lengths of platinum wire) to detect periodicity of magnetism due to the discharge current. (He used needles 5mm, 10mm, and 15mm in length.)
2. Experiments to study the mutual influence of the different parts of the discharge circuit (using a brass wire 1 meter in length).
3. Experiment to determine if the force of magnetization of a discharge can be modified by resistance. (The concept of impedance was unknown.)
   (a) Savary discussed the production of high temperatures in the platinum wire during the discharge.
   (b) He studied whether tempering of the steel needles affected the outcome of the magnetization.
   (c) He described the sense and intensity of the magnetization of the steel needles.
4. Experiment to study the influence of the hardness of the needles on their magnetization.
5. Experiment to study the influence of the diameter of the needles on their magnetization.
6. Experiments to detect periodicity of magnetism on steel needles using a brass wire helix wound on a hollow wooden cylinder 9cm long, about 6.5mm in diameter. He discussed:
   (a) the quantity of electric fluid in a Leyden bottle;
   (b) the experiment of Arago in which two helices were used, wound in the same sense and placed one within the other;
   (c) an experiment where two helices were wound in opposite senses and placed one within the other;
   (d) the effects from systems consisting of 3 or 4 helices enclosed one in the other and turning alternatively in opposite senses.
7. Experiment to magnetize 3 needles placed together in the same helix using the same discharge. The needles were respectively 5mm, 10mm, and 15mm in length.
8. Experiments in reduction or augmentation of magnetism by the use of copper, silver, and of tin sheathing, of needles placed in the helix.

NOTE. Savary mentioned that in order to eliminate the effect of terrestrial magnetism, one always places the needles during the discharge in a direction perpendicular to the magnetic meridian.

> "All the phenomena conduce this hypothesis, which in fact depends, not only on intensity, but the sense of magnetism following the laws by which small movements are amortisized in the wire, in the medium which surrounds it, [and] in the substance which receives and conserves the magnetization."
>
> . . . . "An oscillating pendulum in an atmosphere . . . is an example of this genre of movement."

So, therefore, Savary's findings can be summarized for their comparison with the similar experiments conducted by J. Henry. Thus:

(a) the needles are made to oscillate in time (dynamical phenomenon);

(b) each needle possesses a sense of magnetization whatever is the distance of the needle to the nearby wire;

(c) "an electric discharge is a phenomenon of movement." there are alternatives of opposite magnetisms that are observed at diverse distances from a conductor;

(d) "the electric movement during the discharge is composed . . . of a [train] of oscillations transmitted from the wire . . . to the surrounding environs [which] soon dies . . . ."; and,

(e) the oscillations have a finite amplitude.

The 1826 studies by Savary on the oscillatory nature of the discharge current were also analyzed a year later by Gerrit Moll of the Netherlands, and were mentioned elsewhere at that time, as science news items.[17,18]

3. The Researches of Joseph Henry Concerning the Oscillatory Nature of the Leyden Jar Discharge

In 1835, Joseph Henry[6] propounded a theory concerning his observations of changes in the sense of magnetization (i.e., changes in polarity) and changes in the amplitudes of magnetization of steel needles that were exposed to the action of the discharge current. I think that this theory is but an evolutionary step to what I call his mature theory of 1842 on the subject of oscillation. A summary of his findings is made in Table II.

Table II.—Henry's 1835 experimental discoveries published in "Contributions, No. II"

(a)	the direction of the magnetic polarity of the needles varies with their distance from the wire
(b)	this action of inducing magnetic polarity is periodical
(c)	hypothesis of an induced secondary current oppositely directed in the region of the wire; and then a tertiary at a yet greater distance, oppositely directed to the secondary current, etc.

(a) and (b) are the same statements as given by Savary in 1826-7. Hypothesis (c) describes a dynamical notion occurring in time, which implies the existence of higher order but weaker currents at greater distances from the discharge wire. This could be considered as a rough equivalence for an alternating electromagnetic field.

In 1838, Henry published his "Contributions, No. III".[7] A synopsis of his findings about discharge current appears in Table III.

Table III.—Henry's 1838 experiments results on the magnetism of discharge currents and currents induced from sparks from the prime conductor of a generator

(a′)	the direction of the magnetic polarity due to the secondary current, varies with its distance from the primary circuit
(b′)	the action of inducing magnetic polarity from the secondary circuit is periodical
(c′)	the intensity of the induction decreases with increasing distance from the wire

Other than studying magnetic periodicity due to the secondary current, this 1838 study adds nothing essentially new to the 1835 study. In Henry's 1842 publication[10] "Contributions, No. V", he explicitly mentions that an electric discharge is alternating (oscillating), and he proposes the mechanical mechanism of a Franklin fluid. Helmholtz on the other hand, in his independent discovery of the oscillatory character of a discharge (in 1847) which he derived from the principle of the conservation of energy applied to electricity, did not attempt to provide any such mechanism, but he did provide a mathematical foundation for his theory. At that time, the Weber-Fechner theory had just been proposed in 1845–6, which exerted influence on Helmholtz's researches into his application of the concept of the conservation of energy to electricity.

It was left to William Thomson (later Lord Kelvin) in England, to provide a mathematical theory to describe electric oscillation in 1853.

In articles 113–134 of his 1838 publication,[7] Henry described experiments demonstrating oscillatory characteristics of the discharge current. From these experiments he showed 1, the discovery of a difference in the direction of galvanic (d.c.) currents and ordinary (a.c.) currents of the different orders; and 2, he conceived the idea that the direction of the currents might depend on the distance of the conductors. This latter idea is theoretically the same as that which was proposed by Henry in 1835. Henry noted in article 116:[7]

> "When a discharge from the half gallon jar was passed through one of these [narrow strips of tinfoil], an induced current in the same direction was obtained from the other. The ribands were then sep[a]rated, by plates of glass, to the distance of 1/20th of an inch; the current was still in the same direction, or plus. When the distance was increased to about 1/8th of an inch, no induced current could be obtained; and when they were still further sep[a]rated the current again appeared, but was now *found to have a different direction, or to be minus*. No other change was observed in the direction of the current; the intensity of the induction decreased as the ribands were sep[a]rated. The existence and direction of the current, in this experiment, were determined by the polarity of the needle in the spiral attached to the ends of the ribands."
>
> Art, 134. ". . . the facts here presented . . . appear to be intimately connected with various phenomena, which have been known for some years, but which have not been referred to any general law of action. Of this class are the discoveries of Savary, on the alternate magnetism of steel needles, placed at different distances from the line of a discharge of ordinary electricity. . . ."

Compare the above statement from 1838 with his statement of Feb. 1835, found in Henry's publication[6] "Contributions . . . No. II . . . ."

> "When a current is transmitted through a wire, and a number of small needles are placed transverse to it, but at different distances, the direction of the magnetic polarity of the needles varies with their distance from the conducting wire. The action is also periodical; diminishing as the distance increases, until it becomes zero; the polarity of the needles is then inverted, acquires a maximum, decreases to zero again, and then resumes the first polarity; several alterations of this kind being observed. Now this is precisely what would take place if we suppose that the principle current induces a secondary one in an opposite direction in the air surrounding the conductor, and this again another in an opposite direction at a great distance, and so on. The needles at different distances would be acted on by the different currents, and thus the phenomena described would be produced."

Henry seems to have applied to the notion of electric oscillation, a mechanistic fluid conception. The notion of electric fluids with hydrodynamical properties had already been conceived of at an earlier date. Ben Franklin

proposed a single electric fluid in contradistinction to a two-fluid theory. Objections to Franklin's theory were overcome by an ad hoc hypothesis provided by Franz Ulrich Theodor (Theodosius) AEpinus in his book *Tentamen theoria electricitatis et magnetismi* [*"An Essay on the theory of electricity and magnetism"*]". His book was published in the year 1759 by the Imperial Academy of St. Petersburg.

It is important to remember that Henry developed this hypothesis in relation to the dielectric wall of the condenser, and had probably reasoned that the alternating current flow could explain the open circuit of the conduction current interrupted by the non-conducting wall of the condenser. Maxwell had not yet developed his own notion of the displacement current $\partial_t \mathbf{D}$ which allowed the closure of the conduction current through the wall of the condenser.

Henry's laboratory notes[8,9] of June 1st and 2nd of 1842, document the progression of his magnetization experiments which led to his 1842 publication.[10] The principal new finding reported in this 1842 paper, with regard to the oscillation of the discharge current, stemmed from "a new examination of the phenomena of the change in direction of the induced currents, with a change in distance, etc." This went a step beyond Savary's discoveries, in that Henry introduced the concept that oscillation can be induced by the process of induction, to occur in currents of higher orders, however feeble they might be. This is the basic notion of the working principle of the transformer device.

4. The Researches of Helmholtz and of Knochenhauer on Electric Oscillation

In the year 1847, there appeared in print an extensive treatise by Hermann Helmholtz,[5] a physician and physicist, in which he described his theory of the conservation of energy. In one section, he described the energy equivalent of the electrical processes, and one can see how heat energy and electrical energy have an intimate connection, both being but modes of energy. Thus:

> [page 33]
> *"The energy equivalent of the electrical processes"*
>
> ⋮
>
> "Riess *) has shown through experiments, that" . . . [in the circuit of the discharge current, he] "developed heat proportional to the value Q/S. With S he designates only the surface area of the coating of the [Leyden] flask . . . . Out of his experiments has Vorsselmann de Heer **) furthermore followed, as like Knochenhauer***) on his own, that the development of heat from the same charge of the same battery remains the same . . ."

"It is easy to explain this law, as soon as we imagine to ourselves the discharging of a battery not as a one way movement of the electricity in one direction, but as a back and forth fluctuation of itself between the both coatings, in oscillation, which becomes ever smaller, until the entire kinetic energy itself is annihilated through the sum of the resistances."

*) "Poggd. Ann. XLIII 47."
**) "Poggd. Ann. XLVIII 292. See there the observation of Riess. Especially p. 320."
***) "Ann. LXII 364. LXIV 64."

On page 32 of his 1842–3 paper,[11] K. W. Knochenhauer mentioned his conception of electric oscillations in a stressed aether. He was in agreement with the views of Michael Faraday on the nature of the dielectric, except that Knochenhauer developed a view in which an electric aether impregnated the dielectric material of the condenser, as well as the space surrounding it. He stated that (English translation from German):

". . . I will call this the electric stress of the aether. This will arise through the continued charging, and comes finally to such a degree, that the non-conductor can not further resist its congestion, and the electric oscillation of the stressed aether follows. For namely nothing other than as a singular oscillation, whose kind and manner is yet to be found, do I consider to be the spark."

He placed a great emphasis on the study of the electric spark. From the above remarks, it is evident that he believed an oscillation was transmitted by means of a stressed electric aether. His concept preceded the researches of J. C. Maxwell on the electromagnetic theory of light, by 21 years. These remarks by Knochenhauer on oscillation were made in 1842, the same year in which Prof. Henry published his mature theory on the oscillation of the discharge current, on the other side of the Atlantic Ocean. But Prof. Henry considered these oscillating currents as oscillations of a hydrodynamical electric fluid. He did not consider the properties of such a fluid, as to whether it was viscous or ideal, compressible or incompressible; but merely assumed its existence.

In Europe, a number of researchers began to come to grips with the theory of electric oscillation in the decade of the 1840s. Amongst the European researchers, H. W. Dove[3] mentioned the researches of both Savary and Henry. And W. G. Hankel[4] discussed Savary's 1826–7 researches with the magnetization of needles. Hankel discussed Ampère's theory of magnetism, whose hypothesis concerning magnetism he supported, and he discussed Dove's 1841 paper in opposition to it. And he also mentioned the work of Marianini, Henry, and Riess.

Peter Theophil Riess, was familiar with the researches of Henry.[14,15] However, in 1840, he did not accept the theory of electric oscillation, in this, the early part of his career. This can be seen from his remarks, which I have translated from his 19th latinic German.[13]

> "How impermissible is the conclusion of an anomalous magnetization being dependent on the change in the current direction, relative to Savary's experiments, that it depends on the mass and the hardness of the magnetized needle, one must therefore declare about the secondary current, that it is at this or every distance [from the primary] changing its direction, according as the one or the other needle itself is employed in the proof."

This shows that Savary's theory of electric oscillation was not universally accepted by 1840.

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Identification of a Superforce in the Einstein Field Equations

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ABSTRACT

The Einstein field equations provide the underlying principles to theories of gravitation, the big bang, black holes, and cosmology in general. Many variants of these equations have been developed by Einstein and subsequent investigators. These variants include differences in mathematical form, components, arithmetic signs, and the presence of particular constants, and corresponding mathematical solutions. The objective of this paper is to examine the variants of the Einstein field equations where the combination of fundamental constants c^4/G occurs. This combination of the speed of light, c, and the universal gravitational constant, G, has the units of force. Significant relationships of this force to the Planck mass, Planck length, cosmic numbers, color force between quarks, and the Einstein field equations are derived and discussed. The characteristics of c^4/G fulfill predictions for the superforce.