

# A Discussion of the Life of Heinrich Friedrich Emil Lenz

J. B. Tooker  
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## Abstract

Heinrich Friedrich Emil Lenz was a precise and devoted scientist pioneering the field of electromagnetics while leading the way in recording and preparing his experiments, now known as scientific method. The detailed and complete methods of his work have given researchers the world over a standard to live up to. The record of his personal life, on the other hand, did not get as much of his attention. Lenz is best regarded as a precise investigator rather than a gifted innovator. His dutiful research led him to the Law that bears his name.

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Throughout the course of human history, people have sought to describe the mysterious world around them. The effects and implementations of electromagnetics is a fairly late but explosive study. Although first ‘discovered’ before 500 BC, most research in this field did not begin until the 17<sup>th</sup> century (Whittaker; Peters). Heinrich Lenz began his research as many of the fundamental, but separate, laws governing electromagnetism were being established. His work related the laws of electromagnetism with themselves and other physical laws, though not to the extent or prestige of J. C. Maxwell.

Heinrich Friedrich Emil Lenz was born and raised in the town of Dorpat, although it is now known as Tartu, in Estonia. He studied at the University of Tartu from 1820 to 1823 in the area of theology, but soon he switched the study of physics (“DGPT - Heinrich Lenz”). After graduation, Lenz accompanied Otto von Kotzebue on a worldwide voyage as geophysical scientist. His work during this voyage focused on climatic conditions as he “made extremely accurate measurements of the salinity, temperature, and specific gravity of sea water,” (“Heinrich F. E. Lenz Biography”). Right from the start it is seen how well Lenz kept notes on his findings and the accuracy of his measurements. This talent will contribute greatly to his later discoveries (“Heinrich F. E. Lenz Biography”).

Though a biological record of Lenz’s life is not available, it is seen from his publications that Lenz was an energetic and intellectually gifted man. Scientists are not apt to leaving records of their lives, while even the least well-known literary author “takes occasion to leave a sufficient record of his life to show what the manner of the man was,” (Stine 64). It can be assumed that Lenz was a clever and able man, just as it can be assumed of most scientists, when knowledge of their life is incomplete. The titles of Lenz’s first publications give the first indication of Lenz’s character. In chronological order they are:<sup>1</sup>

- ★ “On the Temperature and the Salt-Content of the Water of the Ocean at Different Depths”
- ★ “Report on a Journey to Baku”
- ★ “Physical Observations Made during a Voyage around the World with Captain Von Kotzebue, in the Years, 1823-6”
- ★ “On the Comparative Quantity of Salt Contained in the Waters of the Ocean”
- ★ “On the Influence upon the Movements of the Beam of a Balance, Due to Bodies at Different Temperatures in its Neighborhood”
- ★ “On the Variations in Height which the Surface of the Caspian Sea Has Suffered to April of the Year 1830”

The seventh published paper – the first of great significance – entitled “On the Laws which Govern the Action of a Magnet upon a Spiral, when it is suddenly Approached toward, or

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<sup>1</sup> Note: these titles are English translations (Stine 66-67).

Withdrawn from it; as the most Advantageous Method for Constructing Spirals for Magneto-Electrical Purposes,” is an indication of Lenz’s professional transition to electromagnetic research in 1832. Up until the 1820’s, electric and magnetic phenomena were considered separate subjects. In 1827 Ampère published his electromagnetic theory based on Oersted’s observations (Peters). Lenz’s seventh paper shows the true nature of Lenz as a scientist. The fruits of this paper were derived from the reproduction of Faraday’s published experiments, thus making the identification of Lenz’s original initiatives a challenge. Both Henry and Faraday published papers in the same area earlier that year, October and February, respectfully (Stine 68).

While the originality of Lenz’s early papers may be ambiguous, what is clear is how accurately and completely Lenz carried out his experiments, often to a finer precision than the original scientist. In addition to Faraday’s experiments, Lenz measured the forces and magnetic actions caused by a spiral abruptly drawn away and brought towards a magnet (Stine 70). This precise, quantitative research is what separated Lenz from his contemporaries who focused on more qualitative research.

Today, quantitative findings are the basis of modern research, and science places less emphasis on the imaginative and the qualitative innovation approach (Stine 70-71). The use of ‘scientific method’ shows this. Continuing this type of research, Lenz outlined measurable parameters that could affect these “electromotive spirals” before digging blindly into this new field of research. These characteristics were:

1. The number of convolutions in the spiral
2. The Breadth,
3. Thickness,
4. And substance of the convolutions (Stine 71).

To validate an experiment, it must be reproducible by others. Lenz takes great care in describing the instruments he used, so that others may know how accurate his findings were. At this time in history, one was not able to go to an electronics shop and simply purchase an accurate multimeter. His galvanometer was “constructed with Nobili’s double or astatic needle; and was wound with 74 turns of wire, 0.635mm in diameter. Describing other details of the apparatus, the paper states, ‘I wound the electromotive wire about a soft iron cylinder, which served as an armature, and was filed smooth and flat at those places, where it was laid on the poles of the magnet. As the removal of the armature can be performed in a more certain, prompt and uniform manner than the placing of it on the poles, I have, in all my following experiments, given the results which were obtained by pulling away the armature, or by the sudden removal of magnetism from the iron,’” (Stine 71-72). Lenz takes this care in every step of his reports to assure others that his experiments are true to their claims.

Lenz proceeded to test these variables he had prepared using the recent laws in electromagnetism. Not only did he use these laws but also he fully understood them, having

discovered some of these laws himself before learning of Ohm's work (Ohm 613). In addition to his understanding of the significance of these laws, he also "knew how to combine them quantitatively," (Stine 73).

The results of this study show: "The electromotive power, which a magnet produces in a spiral with convolutions of equal magnitude, and with a wire of equal thickness and like substance, is directly proportional to the number of its convolutions." Defined in C. G. S. units (Centimeter, Gram, Seconds) as opposed to M. K. S. units (Meter, Kilogram, Second, known as SI after 1960) (Stine 74; Rowlett):

$$e = -n \frac{dN}{dt}$$

Continuing his detailed description, in the second experiment of this paper, Lenz describes his apparatus: "I wound the copper wire in six convolutions around a wooden wheel 28 inches in diameter, and placed the wheel on the iron cylinder. After having completed the experiment, I wound six convolutions of the same wire about the same iron cylinder." He found the acting electromotive forces were almost identical leading him to conclude, "The electromotive power which the magnetism produces in the surrounding spiral, is the same for every magnitude of the convolutions" (Stine 75).

Testing different diameters of wire, each 33 feet in length and wound ten times, he noted the resistance of each wire was negligible, despite their different diameters. The electromotive force was constant for each of these three tests. He generalizes, "The electromotive power produced in the spirals by the magnet, remains the same for every thickness of the wire or is independent of it," (Stine 75-76).

The next of Lenz's discoveries states, "the electromotive power, which the magnet produces in spirals of wire of different substances, under like conditions, is the same for all substances," (Stine 76). Modern research often fails to give Lenz accreditation for this simple principle, despite its importance and usefulness. "Ferro-magnetic winding, whose permeability is greater than unity, such materials affect the value of the factor  $dN$  and mask the final result," (Stine 76-77).

Reflecting on the results of previous magnetic research around his geographical area, Lenz states, "Nobili and Antinori, in their first paper on the electrical phenomena produced by the magnet, have already determined the order in which four different metals are adapted to produce the electric current from magnetism. They arrange these in the following order: copper, iron, antimony, and bismuth."

"It is particularly striking that the order is the same as that which these metals occupy, also in reference to their capacity of conducting electricity: and the idea suddenly occurred to me, whether the electromotive power of the spirals did not remain the same in all metals; and whether the stronger current in the one metal did not arise from its being a better conductor of electricity,"

(Stine 77). Lenz proceeded to test copper, iron, platinum and brass in pairs – connected them in series – under the same physical dimensions. No change was found in the resistance of the circuits.

Continuing with his rigorous reporting, he mentions several other factors he took into account and minimized. All of these tests took Thermo-electric precautions as Seebeck had made discoveries in this area ten years before electromotive forces derived from magnetism were discovered. The connection of wires was also addressed: he found a less than point-two percent difference between twisting wires together ten times and using pliers to force and flatten the wires together. Perhaps one aspect that he did not realize was the difference between static galvanometric readings and impulsive deflections, causing error in his current measurements.

Comparing Lenz with his contemporaries at this point of his life shows Faraday and Henry as pioneers in this new field, with Lenz refining and generalizing their discoveries. Though “Faraday showed preeminent genius in seeking after the causes of the new phenomena, and developing the useful working hypothesis of tubes of force. Both Henry and Faraday neglected to attempt any mathematical formulation and deduction from their experiments,” (Stine 84-85). Lenz is the more modern scientist, precise and analytical, methodically examining every aspect of an experiment. Looking only at his early work, one would not be alone in wondering if Lenz did not possessed true genius, but was purely a judicious researcher. Later publications give insight to a better conceptual understanding that is lacking in his early reports.

For a period of time after Lenz finished these electromagnetic experiments, and before starting his more famous ones, he studied electrical resistance and conductivity in metals. Though electrical in practice, these studies incorporate much of his earlier work. He continued to find and explain the generalizations he discovered, while continuing to apply scientific method. Of these studies, perhaps the most intriguing ones dealt with the resistance of a material due to temperature. On June 7, 1833 his paper entitled, “On the Conductivity of Metals at Different Temperatures for Electricity,” was read before the Academy of St. Petersburg (Sting 88). At this time formulas had not been derived that explained his hypothesis. After struggling with his current formulas and initial experiments, he determined that the internal resistance of his battery pushed the uncertainty factor of these experiments past the effects that changing temperature would produce.

At this point Lenz’s ingenuity starts to shine. Faced with a dead end in using a non-ideal battery, he turned to the electromotive spirals to measure the currents needed to explain the temperature dependence. He was now able to determine the exact resistance of each material, and measure these magnitudes very accurately. From these studies, Lenz developed this relationship:

$$Y_n = X + Yn + Zn^2$$

This formula has been improved upon until it became what it is today:

$$R_t = R_0(1 + \alpha t + \beta t^2)$$

Matthiessen is the one usually credited with this relationship, while textbooks hardly mention Lenz, especially English books (Stine 90, 91).

As a standard unit had not been created yet, Lenz defined his own unit of resistance. He defined his resistances as compared to a unit length of copper wire at a certain diameter. In an 1834 paper he disproves Ritchie's observations of conductivity, using simple algebraic expressions showing the relationships of voltage, current and resistance, similar to the works of Ohm and Fechner. The expression he derived is shown below, where  $J$  is current,  $E$  is voltage, and  $W$  is the resistance (Stine 94-96).

$$J = \frac{E}{W}$$

When connecting a real circuit, thus taking into account the wires, this expression is derived for the current, where  $l/c$  is resistance in terms of the unit length of copper:

$$J' = \frac{E}{W + \frac{l}{c}}$$

Solving for  $W$  yields,

$$W = \frac{l}{c} \times \frac{J'}{J - J'}$$

a resistance, standardized to a unit length of copper. Having a setup that would not change under different loads, Lenz was then able to insert resistances,  $R$ , into his system, which would yield their respective currents,  $J''$ .

$$J'' = \frac{E}{W + R} \rightarrow R = W \frac{J - J''}{J''} = \frac{l}{c} \times \frac{J'}{J - J'} \times \frac{J - J''}{J''}$$

This crude and almost roundabout way of accurately measuring resistances yielded results that agreed quit well with those found later by scientists with better and more modern instruments. He tested and determined the conductivity of silver, copper, gold, iron, tin, lead, platinum as well as many other conductors. Using Ohms Law (not called such at the time) as an axiom, Lenz states, "The conductibility of wires of the same substance, is inversely as their length and directly as their cross-section" (Stine 97). And he acknowledges the use of electrodynamic current to find these resistances as sufficiently accurate, while deducing that internal resistances of the batteries and circuits used by other researchers caused their failures and inability to determine this relationship for themselves. Lenz did not discover here (but would later) the impedance effects of materials in an AC system, though his experiments (luckily) did not depend on any of these impeditive effects.

Lenz is most famous for a generalization, bearing the name Lenz's Law. First announced in his paper, "On the Direction of Galvanic Currents Which Are Excited through Electrodynamic Induction," read before the Academy at St. Petersburg on November 29, 1833 (Stine 102). Faraday

stated two laws, though Lenz argued that they were describing the same phenomenon, Faraday stated:

- I) “Between parallel conductors, one of which carries a current, an opposing current is induced upon approach toward, and a current similarly directed upon withdrawal from the first conductor.”
- II) “When a conductor is moved near a magnet, the direction of the induced current depends upon the manner of cutting the magnetic curves,” (Stine 103).

Lenz’s Law was derived from a literal interpretation of Ampère’s hypothesis in an attempt to more accurately state what Faraday had tried to say.

In attacking Faraday’s conclusion, Lenz gives several instances where Faraday’s two laws would be incorrect. His first situation places a conductor perpendicular to a second conductor in which a current circulates. According to Faraday, no current would be induced in this conductor, when moved parallel with itself and, in its plane of movement, parallel with the inducing conductor (Stine 107).

After studying Faraday’s papers, as well as Nobili’s comments on them, he began to seek a common phenomenon that could describe electrodynamic phenomena. After verifying his expectations of Faraday’s experiments, Lenz states (translated into English), “The electrodynamic action of an induced current opposes equally the mechanical action inducing it,” (Stine 111). Lenz’s Law itself is a specific example of Conservation of Energy, not developed until 14 years later (Stine 112).

A simple example, that shows Lenz’s law, is to take a coil of wire and drop it through a magnetic field. When the coil is open-circuited (no current will flow in the wires) it will fall quickly due to gravity. When the coil is short-circuited, it will appear to resist the force of gravity due to the fact that energy is required to induce the current that is now allowed to flow through the coil. Here it can be seen that Lenz’s law is a specific example of the conservation of energy. See Figure 1. A video demonstrating this is available at [http://msdaif.googlepages.com/demo\\_lenz](http://msdaif.googlepages.com/demo_lenz) (Daif).

In 1845 Neumann published this expression derived from Lenz’s Law:

$$E.Ds = -\epsilon v C.Ds.$$

“Where  $E.Ds$  is the electromotive force induced in the element  $Ds$ ;  $v$  is the velocity with which  $Ds$  is moved;  $C$  denotes the magnitude of the resolved action of the induction upon  $Ds$  when unit current is considered to be flowing in this element. The magnitude of  $\epsilon$  is independent of the activity of the induced conductor” under linear induction, which is constant, but is a function of time (Stine 113-114).

Another phrasing of Lenz’s Law from his paper reads, “To each phenomenon of movement by electromagnetism, there must correspond an electrodynamic distribution. Consequently it is only necessary to produce motion through other means in order to induce a current in the moveable

conductor, which shall be opposed in direction to that so produced in the induced conductor of the electromagnetic tests,” (Stine 116). Though fully understanding this law in the realm of electrodynamics, Lenz almost hints at, but does not discuss, its further application in terms of its greatest significance: conservation of energy (Stine 115-116).

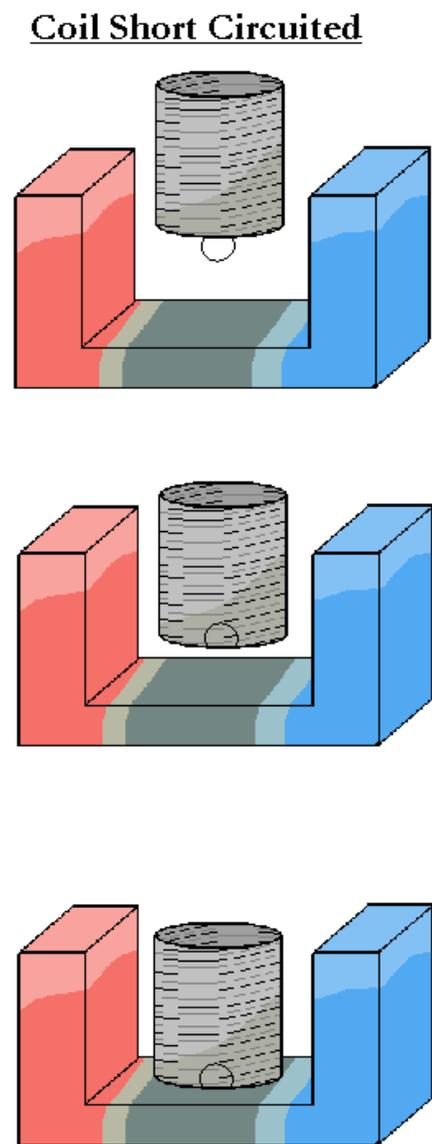
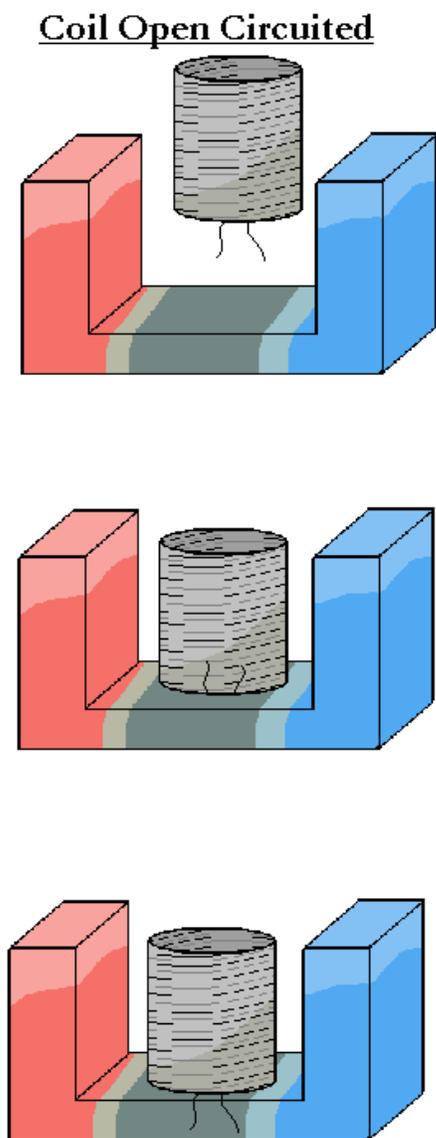
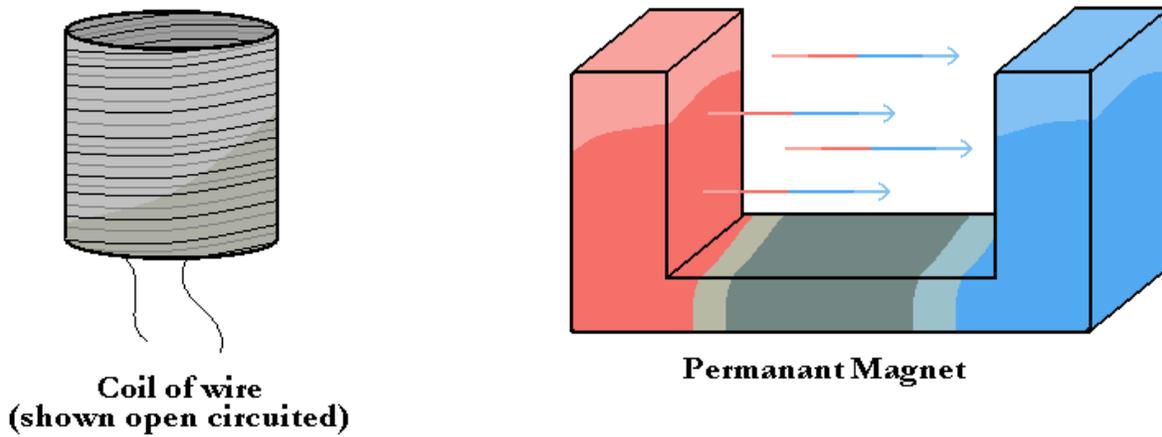
One quickly notices how completely Lenz tests this law. Unlike the work of Faraday, Ampère and many others, Lenz thoroughly tests every aspect surrounding his findings. He comprehensively and logically planned his experiments to be complete and test every variable that could be accounted for, and he was successful. In this paper, Lenz separately compares the similar conclusions of Faraday and Ampère, and others in relation to his law as well as his view of the matter.

Lenz was immersed in the beginning of the study of electromagnetism for the 30 years after 1833. He, Faraday and Henry were the early pioneers of this field. Much of the later work in this scientific area is in the application of the laws found in this short, accelerated research. In commenting on Lenz’s contributions to science, W. M. Stine elaborates, “Neither in his contributions nor investigations can he be called brilliant; he, perhaps, did little, if anything, which would not subsequently have been done: yet all his work was of that solid and enduring character, which forms the foundation of all science. His methods were painstaking and exhaustive: he verified, extended and formulated,” (Stine 129-130).

Lenz’s later works continued to show his dutiful and meticulous manner of experimentation. After Joule released his law for the heating effect of an electrical current, “Lenz verified and extended the investigations in a precise and remarkable manner,” (Stine 132). He eliminated the cooling effects of air by cooling his apparatus far below room temperature, and then he proceeded to test many different metals, followed by taking into account the specific heat of the wires he was using. He also sought to maximize the output of electromotive forces from magneto-electric generators. In these investigations, he charted his data as a waveform using a method that is largely used today.

His life came to an anti-dramatic end as he suffered a stroke on February 10, 1865 while in Rome for medical reasons. He died at the age of 61 (“Heinrich F. E. Lenz Biography”).

Lenz’s scrupulous research methods and recognition of the implications of his electromotive coils make him stand out as one of the great electromagnetic scientists. Despite the lack of originality in his work, Lenz was able to draw conclusions that his colleagues overlooked, especially when it came to quantifying observable – and as Lenz showed – measurable phenomena.



**time** ↓

Figure 1

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