A New Understanding of Electromagnetic Devices:

Auguste De La Rive's Floating Battery

By Marielle Bersalona

In the summer of 1855, De la Rive invented the floating battery: a galvanic pair that is connected by a coil of wire that is placed directly above it and submerged in a tiny floating cell. The entire assembly, which floats in a bigger tank, turns the once excited battery to the right angle to the magnetic needle. The two plates are inserted through a cork and floating in a solution of diluted sulfuric acid. In accordance with Ampere's Theory, a magnet functions to either attract or repel the coil. This battery contributes to a number of significant historical and scientific devices invented in the early nineteenth century. With the purpose of examining De la Rive's floating battery experiment, an important aspect of indulging in the process is examining the historical effects of the discovery. The conceptual aspect of modern physics is contrastingly different from historical discoveries. In the modern day, we are not only discovering new processes but we are also utilizing prior theories. We are building onto these theories to ultimately analyze De la Rive's floating battery and the electromagnetic device's contribution to the quantization of electricity.

Introduction:

Auguste De la Rive – Personal History and Scientific Contributions

Auguste De la Rive, one of the pioneers of the electrochemical theory of batteries, was a Swiss scientist. In 1823, De la Rive was appointed the position of Chair of Natural Philosophy at the Academy of Geneva. His research on the galvanic cell, an early form of battery, in 1836 advanced electrical theory. He agreed with the English physicist Michael Faraday that chemical activity produced voltaic power. He created the method for electroplating gold onto silver and brass, and was awarded a prize by the French Academy of Sciences. Furthermore, he observed that the ozone is produced when electrical sparks travel through oxygen during his studies on the discharge of electricity via gases.

I focused on a particular battery of De la Rive's many studies (hereafter referred to as the floating battery) that is in the Princeton archives along with several other similar models. One of only two in the world, the other floating battery is located in the Smithsonian Museum. In 1821, De la Rive crafted and documented his battery in his book, "Des Mouvements Vibratoires que Déterminent Dans les Corps, et Essentiellement Dans le Fer, la Transmission des Courants Electriques et Leur Action Extérieure" which consisted of a collection of his notebooks and scientific discoveries. Nonetheless, his analyzation of electromagnetic currents and the concept of galvanism was introduced first by Joseph Henry. The ideas were similarly experimented by Michael Faraday, in which De la Rive references in his work and vise versa.

To develop an understanding of the floating battery, I inspected, tested, and constructed several experiments that similarly utilized magnetic fields and their correlation to electromagnetic devices in the solution of water, rather than sulfuric acid. I studied the historical significance by reading Joseph Henry's "Lectures on Electricity and Magnetism" and the multiple volumes of Michael Faraday's "Experimental Research of Electricity" which collectively explained the Ampere's Theory, the process of induction, and galvanism. Henry and Faraday paralleled each other's work on magneto-electric induction which is evident in the floating battery experiment.

The floating battery differs from other electromagnetic devices used for experimentation during the early nineteenth century as while carrying an electric current, De la Rive proved that a coil of wire behaves similarly like a straight wire when it comes to interactions with a magnet. However, the apparent magnetic polarity of the coil is caused by the circular direction in which the current travels. This discovery prospered the experimentation period of electromagnetism.

Purpose of the battery:

De la Rive created a floating battery, which allowed the two electrodes to float in an electrolyte while being supported by a cork, to demonstrate electromagnetic phenomena. The terminals were wired to a coil or solenoid. This device, which acts like the needle of a traditional compass, generates its own magnetic field by the passage of current through the coil and, being mobile, would adopt a certain position with respect to the magnetic field of the earth or when encountered by another magnet (see model for reference).

Scientific Theories Applied:

Faraday's Law of Electrolysis

Faraday was the first to recognize the distinction between materials that allow an electric current to flow through them in solution. He discovered the electrolyte and the ion, but his most significant contributions to science were his work on electromagnetism, which led to the growth of modern electric motors, generators, and transformers. Faraday was a renowned experimenter. His discoveries in electromagnetism are documented in his notes.

Faraday thoroughly investigated the rotating effect of the floating battery. He replicated several of De la Rive's experiments in an effort to relate his own observations of rotating forces to the measured linear forces. He performed this demonstration by inserting two wires from a voltaic cell into a water basin with a small amount of mercury at the bottom to ensure proper contact, similar to De la Rive's battery.

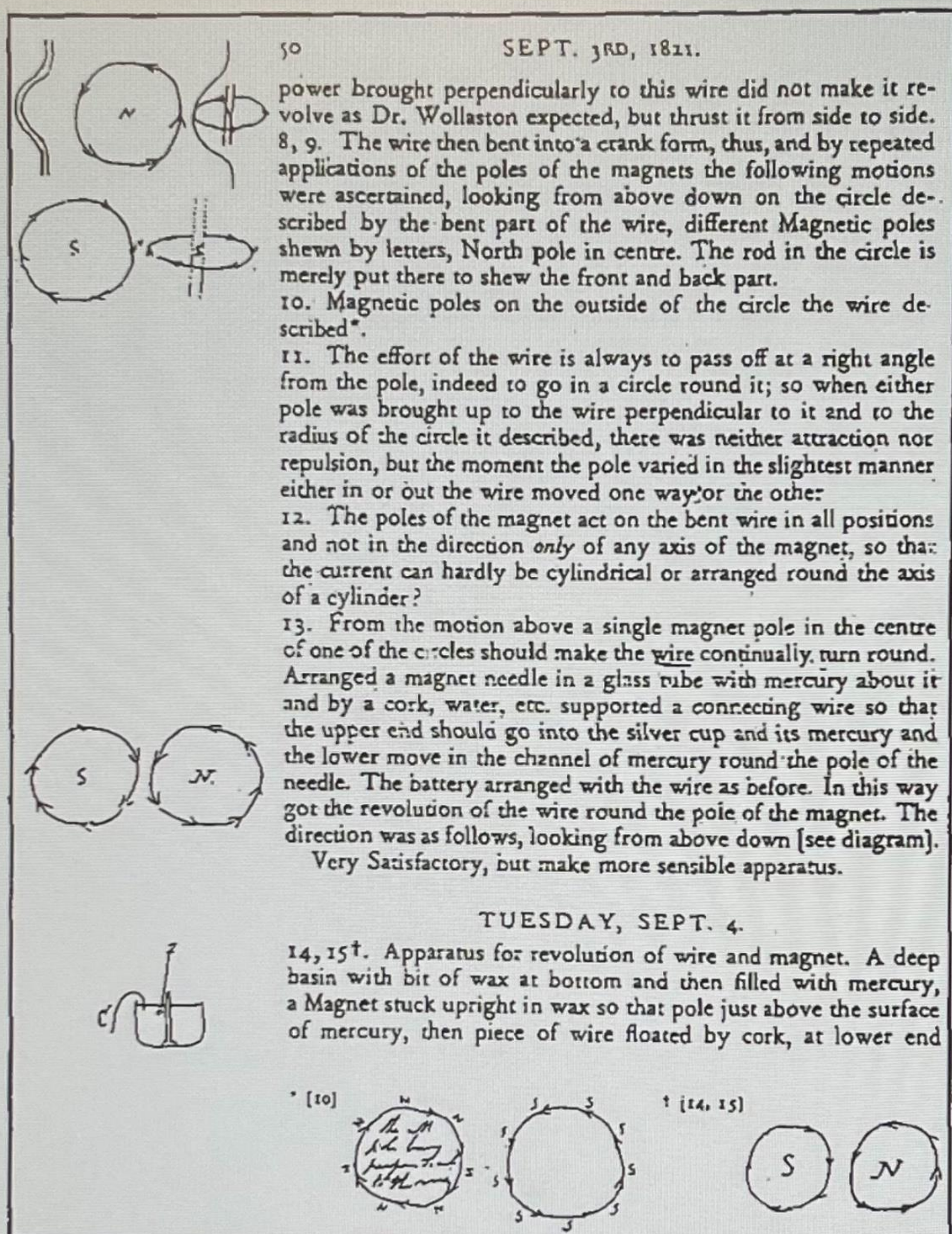
Faraday's Law of Attraction

The basic understanding of the Law of Attraction that Faraday theorized is that an electric current flows through a conductor as the magnetic field surrounding it changes. The magnitude of the voltage is proportional to how rapid the magnetic field is changing. This law suggests that as the magnet (iron bar) is swiftly pushed in the direction of a wire loop the flux passing through the wire loop is decreasing.

Ampere's Theory

If the currents flowing through two wires are in the same direction, they will attract one another; if not, they will repel. The strength of the current has a direct relationship to the force of attraction or repulsion, and the square of the distance between them has an inverse relationship. Ampere's theory is applied to this experiment as the electrodynamics of the battery explains the electrical potential.

A student outlined Faraday's experiments with electromagnetism in relation to the floating battery (see Figure 1).



power brought perpendicularly to this wire did not make it revolve as Dr. Wollaston expected, but thrust it from side to side.
8, 9. The wire then bent into a crank form, thus, and by repeated applications of the poles of the magnets the following motions were ascertained, looking from above down on the circle described by the bent part of the wire, different Magnetic poles shewn by letters, North pole in centre. The rod in the circle is merely put there to shew the front and back part.
10. Magnetic poles on the outside of the circle the wire described*.
11. The effort of the wire is always to pass off at a right angle from the pole, indeed to go in a circle round it; so when either pole was brought up to the wire perpendicular to it and to the radius of the circle it described, there was neither attraction nor repulsion, but the moment the pole varied in the slightest manner either in or out the wire moved one way or the other.
12. The poles of the magnet act on the bent wire in all positions and not in the direction *only* of any axis of the magnet, so that the current can hardly be cylindrical or arranged round the axis of a cylinder?
13. From the motion above a single magnet pole in the centre of one of the circles should make the wire continually turn round. Arranged a magnet needle in a glass tube with mercury about it and by a cork, water, etc. supported a connecting wire so that the upper end should go into the silver cup and its mercury and the lower move in the channel of mercury round the pole of the needle. The battery arranged with the wire as before. In this way got the revolution of the wire round the pole of the magnet. The direction was as follows, looking from above down [see diagram].
Very Satisfactory, but make more sensible apparatus.

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14, 15†. Apparatus for revolution of wire and magnet. A deep basin with bit of wax at bottom and then filled with mercury, a Magnet stuck upright in wax so that pole just above the surface of mercury, then piece of wire floated by cork, at lower end

* [10]

† [14, 15]

Figure 2. Continuation of Martin's transcription (Martin 1932–6, vol 1, p 50). (Reprinted by courtesy of The Director of The Royal Institution.)

Process Explained by De la Rive from the "Esquisse historique des principales découvertes faites dans l'électricité depuis quelques années"

"We surround a bar of soft iron, which is generally given the shape of a horseshoe, of a metal wire which one rolls in a helix and whose whorls are isolated with silk or wax; we pass through this wire, the current of a battery; and immediately the two extremities of the bar become the poles of a strong magnet," (75-76).

Process Explained by De la Rive from the "Annales de chimie et de physique"

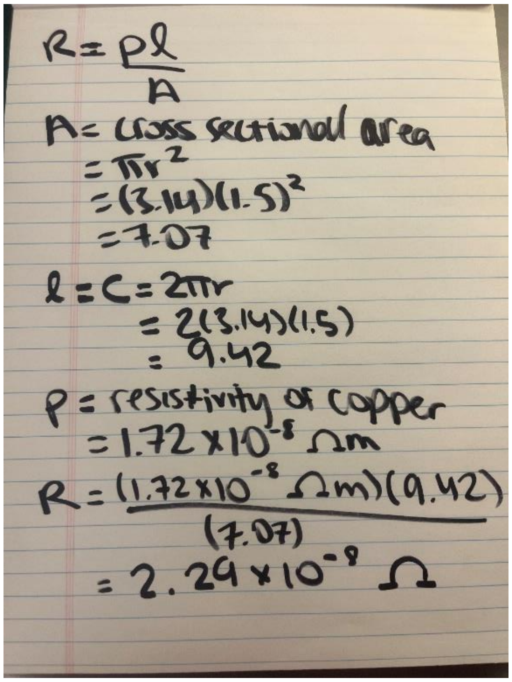
"I used a galvanic tank of twenty couples, old construction and low energy. Thread conductor consisted of two platinum wires of a small diameter; they communicated to the poles of the pile using brass wires of a larger diameter. I sought to increase the effects of my first stack, by reuniting it with a second entirely similar pile, so as to form a battery. This provision device provides me with the opportunity to ensure that the arc metal, which joined the extreme poles, was not the only one capable of deflecting the needle; the inter arc mediator, which united one of the stacks to the other, produced the same effect and follows the same laws. I was able to bring together the effects of these two arcs, and depending on whether they tended, by their respective position, to produce a deviation in the same direction, or in an opposite direction," (208).

A Detailed Look at the Floating Battery:

The floating battery introduced a new perspective of magnetism which demonstrated the development of electromechanics throughout history. From De la Rive's experiment, the idea of an open circuit was developed as both terminals of the battery were not connected to a power source, as well as the concept of floating voltage, which became the ground reference of an electromagnetic system. To analyze from a mathematical and historical perspective, a proper breakdown of each of the elements required to replicate the experiment portrays the apparatus' significance.

Copper wire:

The copper wire is purposed as an inductive metallic property. Copper inductance coils will have extremely low ohmic resistance. Such high inductance will create a significant induced current as a result of a change in magnetic flux, providing noticeable resistance to the flow of current. A multiturn circular loop with a radius of 0.0381 m is created from a single piece of copper wire. The normal to the loop is parallel to a magnetic field. The resistance of the wire is equal to R = ρl/A (where p is the resistivity of the material, L is the length of the wire and A is the cross-sectional area of the wire.). Therefore, a material's resistance is inversely proportional to its area and directly related to the conductor's length and resistance.



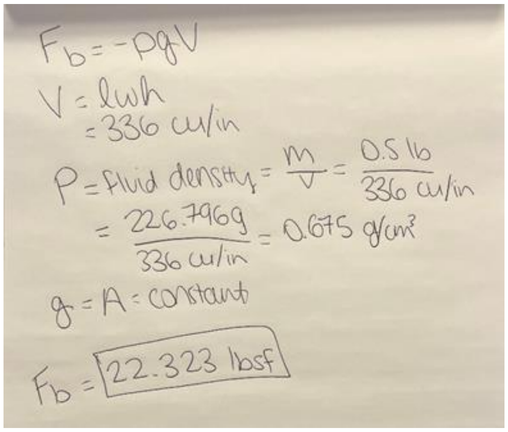
Magnet:

In the floating battery, the magnet was formed by the iron bar and thus the magnetic field can demonstrate how magnetic fields affect magnetic materials, electric currents, and moving electric charges. A force perpendicular to the charge's own velocity and the magnetic field acts on it while the charge is travelling through a magnetic field. A electromagnetic field is produced by a moving electric charge that exerts force on another moving electric charge in a region of space close to a magnet or an electric current. The magnetic field formula explains that the force is perpendicular the field and the current.

$$B = \frac{\mu_0}{2\pi r}$$

Cork:

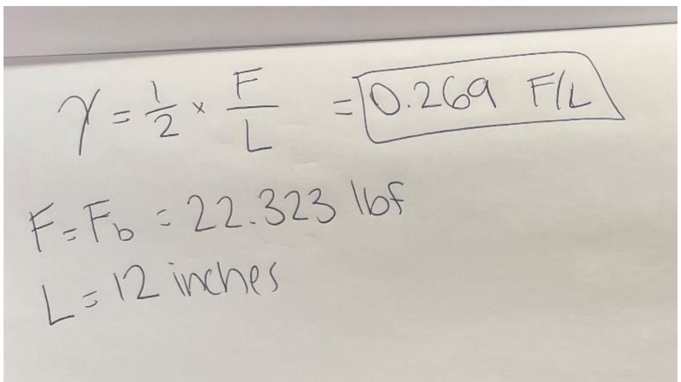
The vertical yet cylindric cork which floats the battery is less dense than the diluted sulfuric acid it sits in. This introduces the law of floatation: when a body floats in a liquid, the amount of liquid that is displaced by the body's submerged portion equals the body's total weight. The weight of the floating body equals the weight of the liquid displaced by its submerged section while a body is floating, according to the law of flotation. The floatability equation or Archimedes' principle explains that upthrust, often known as buoyancy, is an upward force applied by a fluid against the weight of an object that is partially or completely submerged. A fluid column's pressure rises with depth due to the weight of the surrounding fluid. When the buoyancy force was calculated, a positive bouncy of 22.323 lbf was solved for.



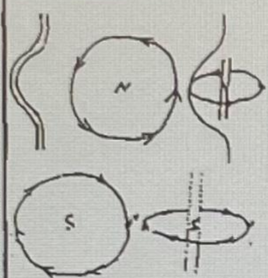
Mercury:

Mercury, which must now be replaced with diluted salt solution or mild acid in compliance with safety standards, was used in several research. Both substances are less conductive than mercury, and gassing tends to shorten the duration of the experiment. Due to the surface tension of the mercury on the cork floats, the wire was inclined at an angle larger than the angle of dip, therefore Faraday employed the Earth's magnetism rather than a magnet when repeating the floating battery experiment.

Ampere discovered that a pivoting wire loop through where a current flowed will revolve in the magnetic field of the Earth. The surface tension equation describes the relationship of cork and mercury that affected the battery's polarity.



A student described Faraday's process in replicating De la Rive's experiment (see Figure 2).



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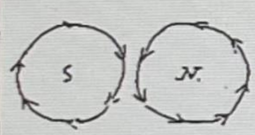

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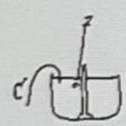

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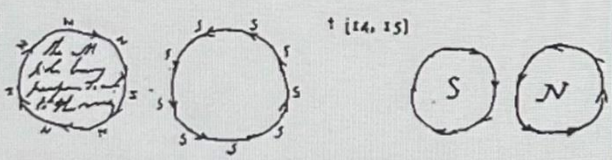


Figure 2. Continuation of Martin's transcription (Martin 1932–6, vol 1, p 50). (Reprinted by courtesy of The Director of The Royal Institution.)

Sulfuric Acid:

De la Rive constructed his apparatus in 3,000 mL of diluted sulfuric acid which was replicated in my experiment with water. Although structurally different liquids, the cork in both cases is less dense than the liquid it floats in. Due to the law of floatability, the replicated experiment modeled the battery's ability to induct. However, note that the density of sulfuric acid is 1.83 g/cm^3 while the density of water converts to 1 g/cm^3.

Experimentation:

Experiment #1 (Part 1) – Tightly Wounded Coil

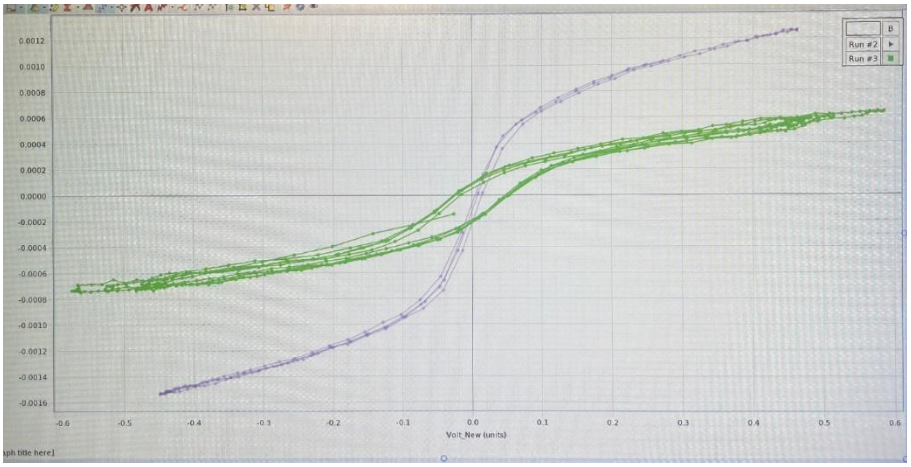
I utilized about a gallon of water which was poured into a plastic container. I used the "Laboratory BC Power Supply" machine with a voltage at five amps of constant voltage and no current. We made a coil shape of magnetic copper wire to mirror De la Rive's ring of the battery. The black and red conductor wires were connected to the machine and placed on the ends of the coiled wire. The two ends of the magnetic wire were shaved with a knife to ensure conductivity as the wire itself is an inductor. I placed the coil on top of the vertical needle. As the needle was attracted to the metal, the needle was magnetized. When I switched the black and red wires, the needle fell out of, or repelled the coil which portrayed the magnetic waves that were created by the electric currents. To introduce the electric field with the water, the needle would only float if it was less dense than the solution it was in, and will float by the level of surface tension. I isolated the needle in a large piece of plastic and it floated due to its magnetism.

Experiment #1 (Part 2) – Larger Radius Copper Circle:

A similar process was implemented for the bigger circle of magnetic copper wire experiment. The same gallon of water with the floating needle was used and the ends of the big circle of copper were shaved for induction. The ends of the wires were connected to the "Laboratory BC Power Supply" machine and the big circle was placed in the water. I uncovered that the needle was attracted to the center of the circle, then towards the edge. The big circle and the needle attracted each other as the needle followed the magnetic field that was created by the induction of electric currents. The needle rotated and was straightforward with the magnetic field independent of how the copper wire moved.

Experiment #2: Evaluating Iron and Steel Within a Copper Coil

First, I crafted a coil of copper metal with many turns. I measured the coil wit the resistance meter of about 0.14 ohms. I connected the black and red wires to the Universal Power Module's Power Amplifier #1 with 10 amps of power. I connected the Ohmite 825FR10 0.1 Ohm 1% 25 Watt Metal Power Resistor 25W, which is 1//10 of magnetic power, to the copper wire. I noted that copper and brass are nonmagnetic objects but it is important to keep ferromagnetic objects at a distance. I used the saturating tool to satur the metal. I wanted an "AC" source that produces current such as current amplifiers. I used the Universal Power Module Quanser and the PASCO Capstone program for the Science Workshop signal generator. I used the CI-6520 Magnetic Field Sensors and the black and red jumper chords to ground the black chord. One end of the black jumper cord was connected to the outut of the Science Workshop 750 and the other end was connected to the Power Amplifier #1. I used the Tektronix TDS 2014C machine to ground the solo scope and formulated the voltage graph from the red and black wires. The machine measured 2 volts per block with a frequency of 10 Hz, an ampititude of plus or minus 5 volts, and a voltage of 5 volts. The black wire from the Universal Power Module was connected to the Ohmite Watt Metal Power Resistor. This process exemplified Ohm's law which states when all other physical parameters, including temperature, are held constant, the voltage across a conductor is directly proportional to the current flowing through it. The current flowed through the wire simulating a complete circuit. I concluded that if the voltage was increased, the thermal heat from the current caused the y-axis to expand on the voltage graph. To measure the voltage, we used the voltage sensor on "Channel B". In the graph, the x-axis measured the voltage and the y-axis measured the magnetic field strength. When examining the magnet, I noticed that the positive end increased the position on the graph and the negative end decreased the position on the graph. Using the voltage sensor, we examined that the polarity was reverse. The signal generator with a magnetic field probe produced a straight line on the graph. When I inserted iron (which obtains a different permeability) into the coil, I produced a saturated, decreasing curve that retraced itself. However, when I inserted steel into the coil, the curve was saturated yet open due to the magnetization that remains and had a smaller slop. This graph represented the hysteresis curves. Therefore, I concluded that iron is a better inductor than steel due to their graphs. To model the hysteresis curves, we used the PASCO Capstone software to generate the graphs.



Modeling the Magnetic Field of a Solenoid Using COMSOL with Mathematical Applications

An equation known as the Biot-Savart law describes the magnetic field produced by a steady electric current. It integrates the electric current's amplitude, path, length, and proximity to the magnetic field.

$$B = \frac{\mu_0 NI}{2R}$$

Correspondingly, A magnetic field may exert a force on charges that are restrained to wires as well A force acting on a current in a magnetic field is given by the equation

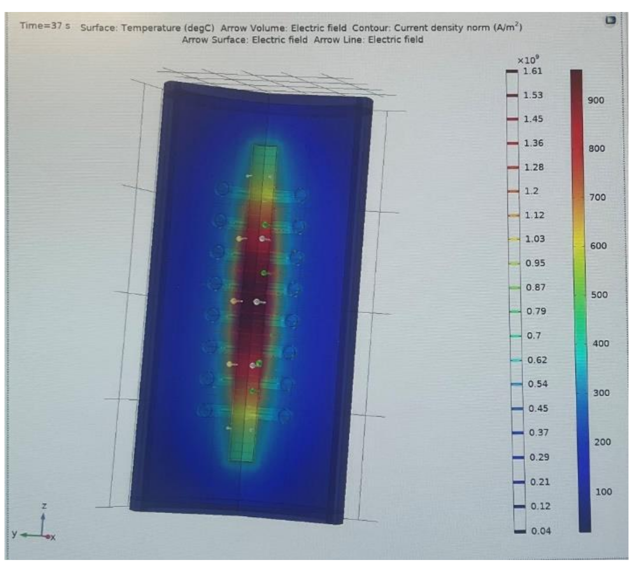
F = I l B or F = IlB sin. With (I) as a scalar factor and (l) as the length of the rectangular space that surrounds the solenoid, we can derive this equation and utilize Ampere's Law to prove or disprove the calculations of the magnetic force that was calculated in COMSOL.

COMSOL Applications

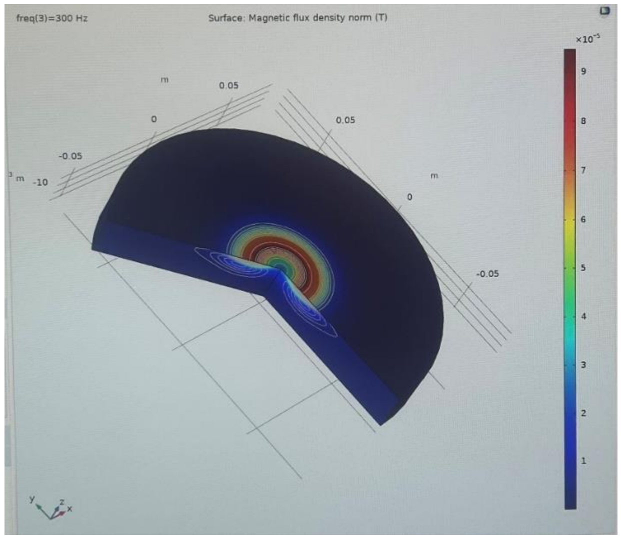
By utilizing the "Derived Values" in results and coding for a "Global Evaluation" of "Study1/Solution1", I calculated a value of 4.9980 x 10^-5 N. By implementing the given values into the Biot-Savart law and the electromagnetism law I concluded with a calculation of 5 x 10^-5.

The study consisted of coding for Study Step 1, which was dependent on the Transience of Frequency, and its subsets which included the Solver Configurations (1 and 2).

This process was simulated in COMSOL which displayed the magnetic flux density of the object in a 3D perspective through a series of coding studies for a particular solution.



From a multisplice or an alternative perspective, the coil's magnetic flux density in a revolved geometric view was simulated for.



The above animation demonstrates the decreasing of the magnetic field over the time interval of three seconds with a constant frequency of 300 Hz with a copper coil simulating the inductive copper wire. \\

How Similar Experiments Relate to Floating Battery

Both experiments correlate to De la Rive's floating battery as I concluded that if a magnet was placed in the middle of the copper wire, the battery would be attracted to its magnetic field. The battery would follow a similar path to the needle as the object would float in the diluted sulfuric acid.

To conclude, Auguste De la Rive's floating battery explored and introduced the early findings of electromagnetism which were enhanced by Michael Faraday and other prominent members of the scientific community. From an analytical perspective, the inductance of the wire mathematically corresponds with the coded simulation in COMSOL Multiphysics from a 3D linear immobile model. The floating battery today is part of the apparatus collection of Princeton's Mechanical and Aerospace Engineering department and is also present at the Smithsonian Museum for preservation.