Magnetic Fields
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I. Introduction

This experiment was meant to examine the strength of a magnetic field in two separate situations. The study of magnetic fields is a valuable topic in physics due to their use in a variety of practical and industry applications in engineering. The first part of this experiment examines the strength of a magnetic field encapsulating a conducting rod producing a current flow. The magnetic field strength, *B*, can be examined by using Equation 1. Due to the perpendicular relationship between the examined current flow to magnetic field we can expect the relationship between *B* and the electromagnet current *I* to be linear.

$$\vec{F} = i\vec{L} \times \vec{B} \tag{1}$$

In part 2 of this experiment Faraday's Law was used to observe how a changing magnetic field due to an induction coil within a closed loop induced an electromotive force (EMF). We can use Faraday's Law to calculate the EMF while also measuring the EMF by looking at the voltage vs time graph of the system. For both parts of the lab the strength of the magnetic field under different conditions was observed.

II. Method

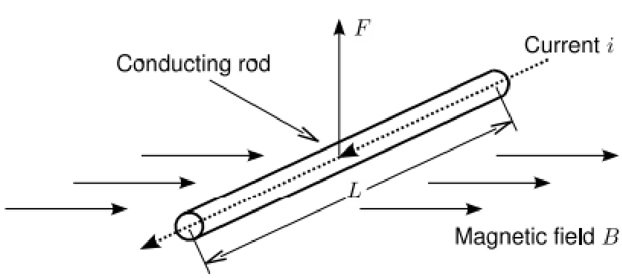

Figure 1: Conducting Rod in Magnetic Field Scenario

For the first part of the experiment, we had a conducting rod of length *L* carrying current *i* and being held up by a current balance. Weights were placed at the opposite end of the balance to help level the apparatus. An iron, c-shaped, electromagnet wrapped in coils and with its own power supply was used to surround the rod with current *I* which was in the opposing direction as *i.* A separate power supply was used on the conducting rod to produce *i.* The set-up can is visualized in Figure 2.

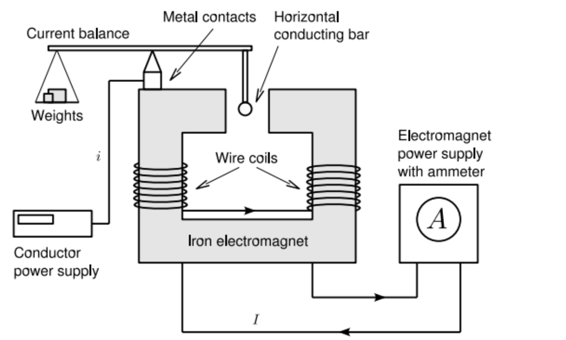

Figure 2: Apparatus for conducting rod part

We set *I* to specific values of 4, 3.5, 3, 2.5, and 2 amps to use as our separate trial events. At each value of *I* we placed 5 different weights onto the balance then adjusted the value of *i* using the power supply connected to the balance until the balance was leveled. We then took the measurements for each situation of the apparatus at every leveled position for all values of *I* for a total of 25 separate data points. We were then able to use this data to calculate *B* using Equation 2 derived from Equation 1.

$$B = \frac{mg}{iL} \tag{2}$$

In part 2 we had a charging magnetic field, Δ*B*, being produced with a pendulum induction coil going between the loop, and we wanted to examine the EMF induced on the coil. We used a magnetic field sensor to measure the magnetic field, Δ*B*, and data studio to collect our measurements.

Figure 3: Apparatus for induced EMF part

Figure 4: Magnetic Field Sensor measuring ΔB

We began this part by moving the induction coil out of the way of the magnetic field then placing the field sensor at the center of the magnetic field for 6 seconds to find the mean value of the magnetic field at that point which was -0.05688 T. We then measured the mean value of the magnetic field from 1 centimeter away from the center and it came out to be -0.05562 T, and then a mean measurement 2 centimeters away for a value of -0.04962 T.

For the final measurement of part 2 we removed the field sensor and allowed the pendulum wand with the induction coil to swing though the magnetic field. We then recorded the peak voltage from the graph on data studio to calculate the induced EMF.

The induction coil that passes through the magnetic field produces a magnetic flux that can be described by Equation 3.

$$\Phi = \int \vec{B} \cdot \hat{n} dA \tag{3}$$

Faraday's Law relates the rate of change of the magnetic flux in a loop to the induced EMF. Using Faraday's Law, presented by Equation 4, we can better understand the processes occurring during this part of the experiment.

$$\varepsilon = -\frac{d\Phi}{dt} = -\frac{d}{dt}(BA) \tag{4}$$

The magnetic flux described by Equation 3 simplifies to $\Phi = BA$ since the area of the loop and the magnetic field are perpendicular to one another.

$$\varepsilon = -NA\frac{\Delta B}{\Delta t} \tag{5}$$

The induced EMF for this scenario can be described by Equation 5 which is derived from Equations 3 and 4. The number of turns in the coil, N, was 200 for this experiment.

III. Results & Analysis

We used the data collected during part 1 and our knowledge of Equation 2 to graph *mg vs iL* for all the values of *I (A)* that were used in our trials. The slope of each of the linear fits, shown in Figures 6-10, is equal to the magnitude of *B*, and each related uncertainty, σ_B, is shown on the plot next to the slope as well.

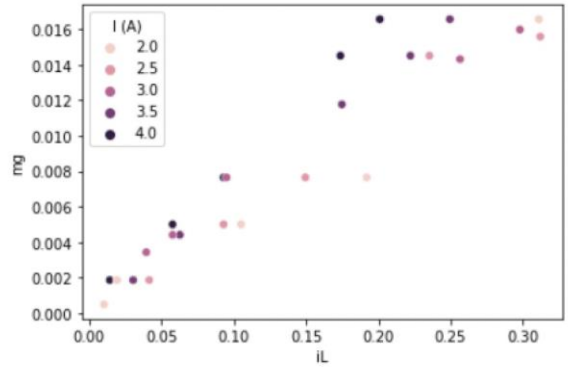

Figure 5: Data chart of Force values from weights vs current flow *i* times length *L*

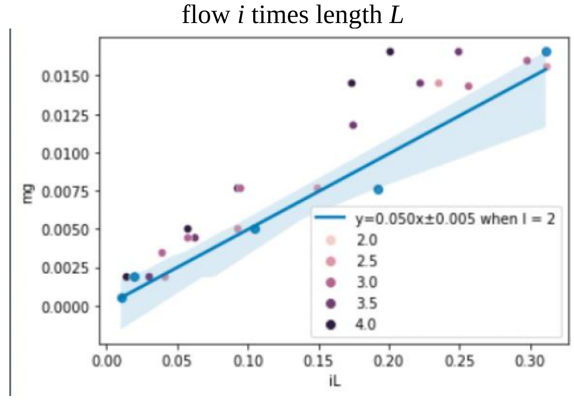

Figure 6: Linear Fit for data points on *mg vs iL* for when *I* was equal to 2 amps

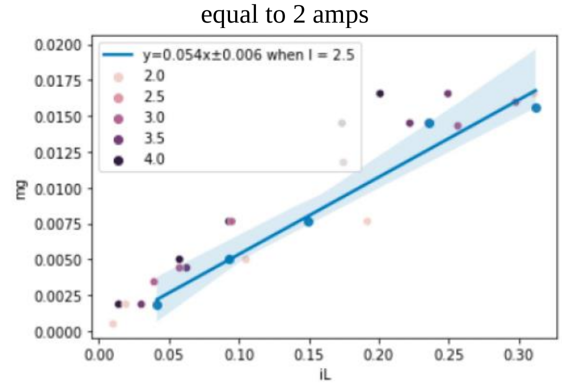

Figure 7: Linear Fit for data points on *mg vs iL* for when *I* was equal to 2.5 amps

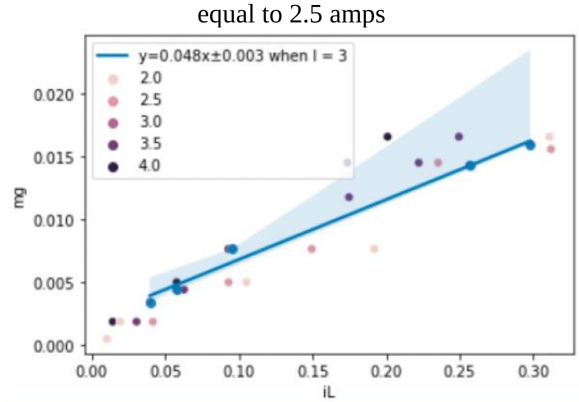

Figure 8: Linear Fit for data points on *mg vs iL* for when *I* was equal to 3 amps

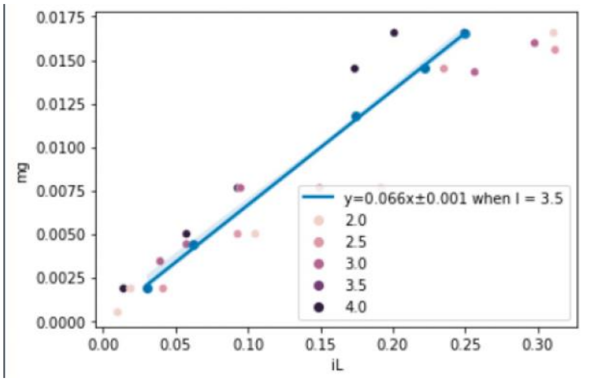

Figure 9: Linear Fit for data points on *mg vs iL* for when *I* was equal to 3.5 amps

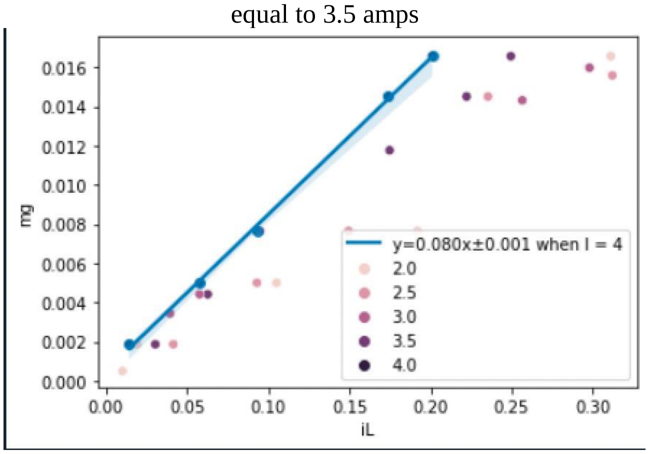

Figure 10: Linear Fit for data points on *mg vs iL* for when *I* was equal to 4 amps

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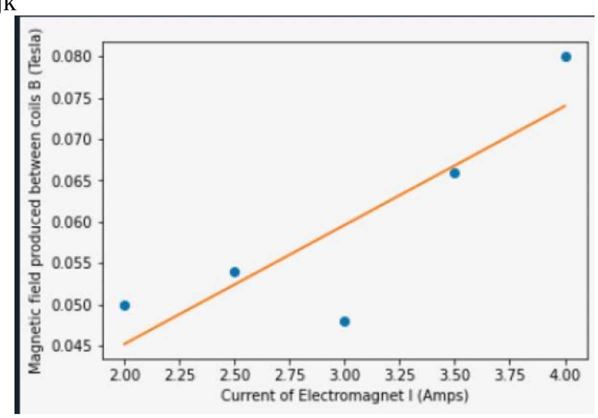

Figure 11: Magnetic Field between coils, *B*, vs Electromagnet Current *I*

After creating the linear fits for each of our *I* trials we graphed the data of *B* vs *I* as I was increased shown in Figure 11. There is a general linear upward trend in Figure 11 which is to be expected because of the perpendicular relationship between current flow and the magnetic field.

Only the horizontal part of the current-carrying rod was considered in our data analysis because the vertical part of the current flow is parallel to the magnetic field lines. This can be explained by the relationship between *L* and *B* in Equation 1 where-in they are two vectors being crossed with each other and the cross product of two parallel vectors will yield zero.

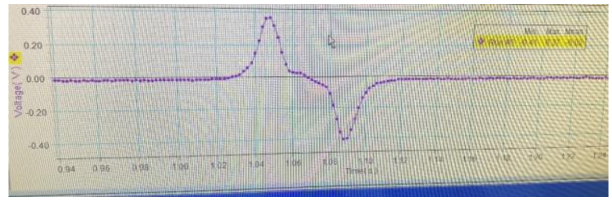

Figure 12: Voltage values (EMF) of induction coil passing through a magnet

Our calculated EMF, ε, value for the first peak was found to be 0.106 (V/M) using Equation 5. The measured value of ΔB at the center of the coil was used along with the change in time Δt of the first peak, and the estimated area of the coil 3.6cm^2 to calculate the EMF. The value of N turns in the coil was given in the lab manual.

The relative error of the measured EMF, which we found to be 0.130 (V/M) at the first peak, relative to the calculated EMF came out to be 18.5%. using the error formula from Equation 6.

$$\Delta = \frac{\varepsilon_{measured} - \varepsilon_{calculated}}{\varepsilon_{measured}} \tag{6}$$

A potential source for the error percentage from the measured EMF to the calculated EMF could stem from slight discrepancies in the Δt when deciphering where exactly the first peak starts and ends. The peak has a very gradual beginning and end, and even small differences in Δt can result in marginally significant differences in the resulting EMF.

IV. Conclusion

In this experiment we examined the magnetic field strength of magnets under a set of magnets under two separate scenarios. In the first, we observed a magnetic field with a conducting rod producing current flow, and calculated the strength of the magnetic field. We found a linear relationship between the magnetic field strength *B* and induced current *I*. In the second part of the experiment, we examined a coil with magnetic flux, and used Faraday's Law to find the induced EMF and found a relative error percentage of measured to calculated EMF of 18.5%.

References

[1] Department of Physics, "Experiments in Physics," Columbia University. New York, pp. 1 5 -22.