Lab 223: Faraday’s Law

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Course: PHYS 121A 016 **Instructor: Subodh Dahal**

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1. INTRODUCTION

1.1 OBJECTIVES

- Demonstrating Faraday's law of electromagnetic induction to familiarize us with the concepts of changing magnetic flux and induced currents that are associated with Faraday’s law of induction.

1.2 THEORETICAL BACKGROUND

Faraday’s Law of Induction states that when there is a change in magnetic flux in a coil, an emf will be induced in the coil. This is known as electromagnetic induction which explains why moving a bar magnet into a coil will create electricity inside the coil. When pushing the bar into the coil, the magnetic flux increases through the coil since the magnetic field strength in the coil increases. Thus, vice versa will cause the opposite to happen when you pull the magnet back out of the coil (decreasing the flux in the coil).

As shown in Figure 1: Is the experimental setup for this lab. A small induced coil is placed between Heimholtz coils. The Helmholtz Coil will be used to create the magnetic flux through the induced coil. Note that the Helmholtz Coils will produce a higher strength magnetic field and will be uniform between the coils. The Helmholtz coils will be connected to a signal generator which will linearly increase or decrease the current over time thus increasing and decreasing the magnetic field strength over time. This constant change in magnetic field will result in a constant change in magnetic flux through the small coil inducing emf.

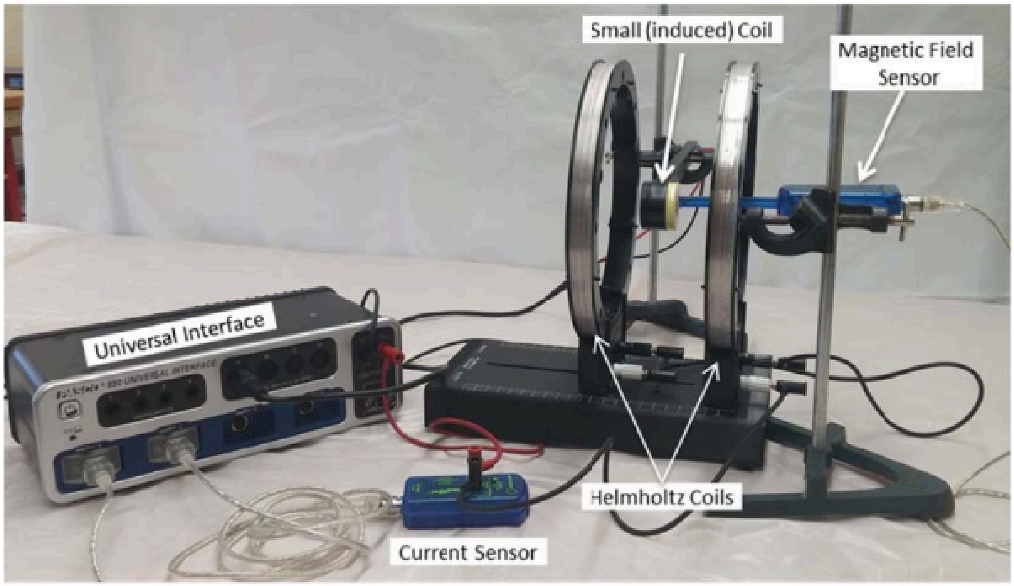


Figure 1. Experimental Setup for Faraday's Law of Induction

The emf induced in the coil by changing magnetic field is measured and compared with the predictions of Faraday's Law.

Magnetic flux Φ_B through the small coil in Figure 1 is given by:

(1) $\Phi_B = \int \vec{B} \cdot d\vec{A}$

When the magnetic flux of the small coil is changing over time, the loop will oppose the changes by inducing emf,

(2) $\varepsilon = -\frac{d\Phi_B}{dt}$

The negative sign in Equation (2) shows that the induced emf and the change in magnetic flux will have opposite signs. This means that the magnetic flux from the Helmholtz coils increases over time that goes through the small coil will induce an emf in the direction that will reduce the amount of magnetic flux change going through it.

If the small coil on wire has, N amount of turns and a cross-sectional area, A is aligned with the uniform magnetic field then:

(3) $\varepsilon = -NA(\frac{dB}{dt})$

Earlier we mentioned that the magnetic field from the pair of Helmholtz coils will be connected to a signal generator.. The small coil is placed in the center between Helmholtz Coils. The Helmholtz coils are connected to a signal generator with varying current through the coils over time. A sensor is connected in series with the Helmholtz Coils to measure the current going through the Helmholtz coils.

$$(4) \quad B(t) = \frac{8.992\times10^{-7} N_h I}{R}$$

N_h is the number of turns in the Helmholtz coil, R is the radius of the Helmholtz coil, and I is the current going through the Helmholtz coil. Since magnetic fields is linearly proportional to the current we can rewrite equation (4) as following:

$$(5) \quad B(t) = 8.992 \times 10^{-7}(\frac{N_h}{R})I(t)$$

As the Helmholtz coils are connected to the varying output we'll make it so that the current through the coils change linearly over time. This change in magnetic field strength is linearly proportional to the change in current over time, giving us:

$$(6) \quad \frac{dB(t)}{dt} = 8.992 \times 10^{-7}(\frac{N_h}{R})(\frac{dI(t)}{dt})$$

Therefore we can combine equation (3) and (6) and have the following:

$$(7) \quad \varepsilon = -8.992 \times 10^{-7}(NA)(\frac{N_h}{R})\frac{dI(t)}{dt}$$

N represents the number of turns in the small coil, A is the cross sectional area of the small coil, N_h, is the number of turns of the Helmholtz coil, and r is the radius of the Helmholtz coil. When these parameters are fixed, the emf is directly proportional to the current through the Helmholtz coils. (The sign of the emf is opposite to the change in current.)

2. EXPERIMENTAL PROCEDURE

Two Helmholtz coils were configured in series with a DC power supply, as well as with a digital current sensor. A smaller coil and magnetic field sensor were placed in the geometric center of the coil system. The smaller coil was configured such that the computer could automatically send a changing current through the small coil. Software was used to vary the current through the smaller coil, as well as the magnetic field produced and current induced over time. The observed changes in magnetic field and emf were then compared to their expected values, given the size and number of turns present in each coil.

3. RESULTS

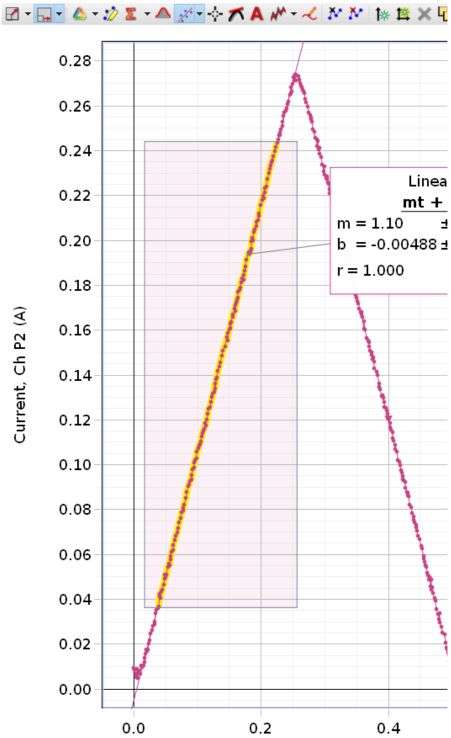
3.1 EXPERIMENTAL DATA

Table 1 diameter: 28.5 mm

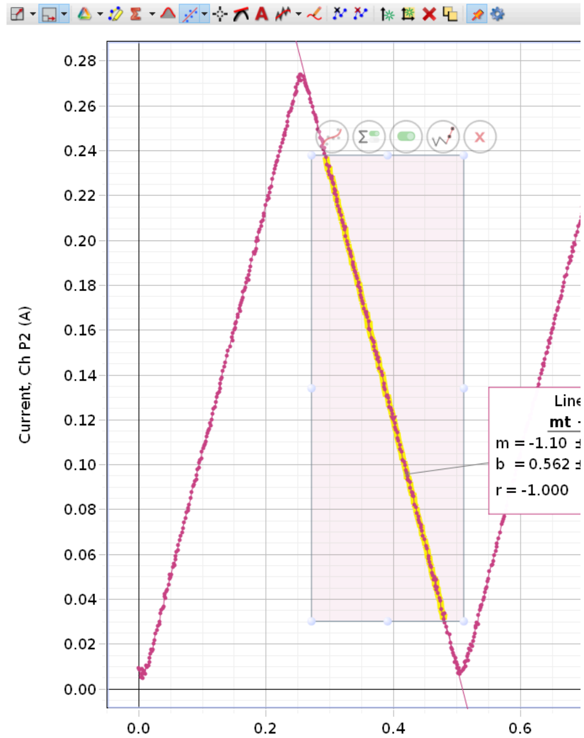
Helmholtz Coil		**Small(induced)Coil**	
Radius (R)	**Number of Turns (N_h)**	**Cross-sectional Area (A)**	**Number of Turns (N)**
0.105 (m)	**500**	**6.38e-4 m^2**	**2000**

Table 2

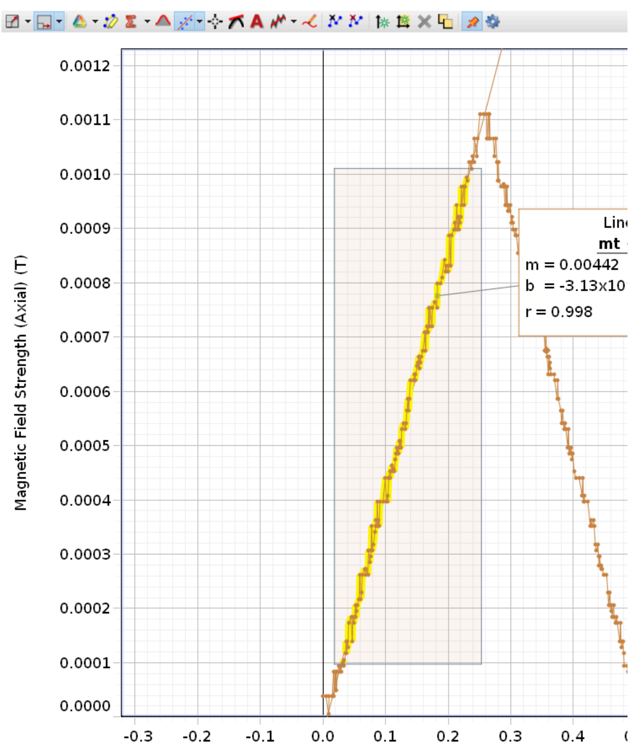
Frequency = 2Hz		**Current increase region**	**Current decrease region**
1	$\frac{dI(t)}{dt}$:Slope in current vs time graph [A/sec]	**1.11 A/s**	**-1.10 A/s**
2	emf: $\varepsilon = -8.992x10^{-7}(NA)(\frac{N_b}{R})\frac{dI(t)}{dt}$ [V]	**-0.00604 V**	**0.00601 V**
3	$\frac{dB(t)}{dt}$: Slope in Magnetic field strength vs time graph [T/sec]	**0.00484**	**-0.00468**
4	Emf: $\varepsilon = -NA\frac{dB(t)}{dt}$ [V]	**-0.00617 V**	**0.00596 V**
5	Experimentally Measured emf [V]	**-0.0067 V**	**0.0068 V**



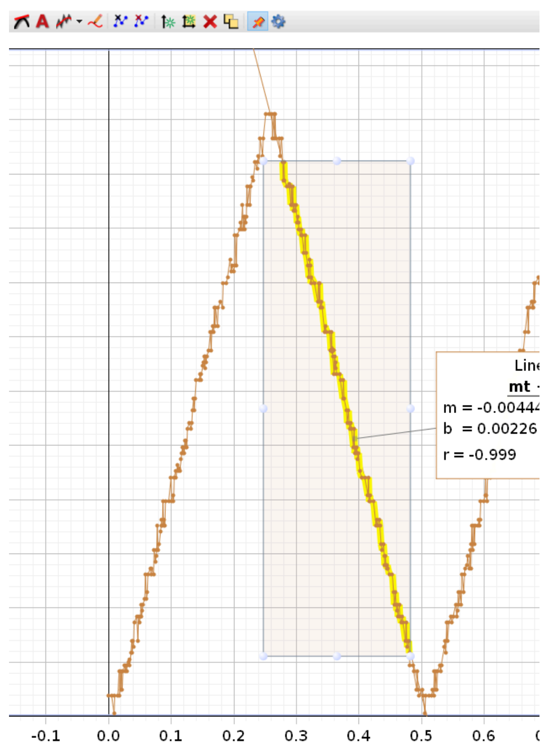
Current through Helmtholtz Coil



Current through Helmtholtz Coil



Magnetic Field Strength through Helmholtz Coils



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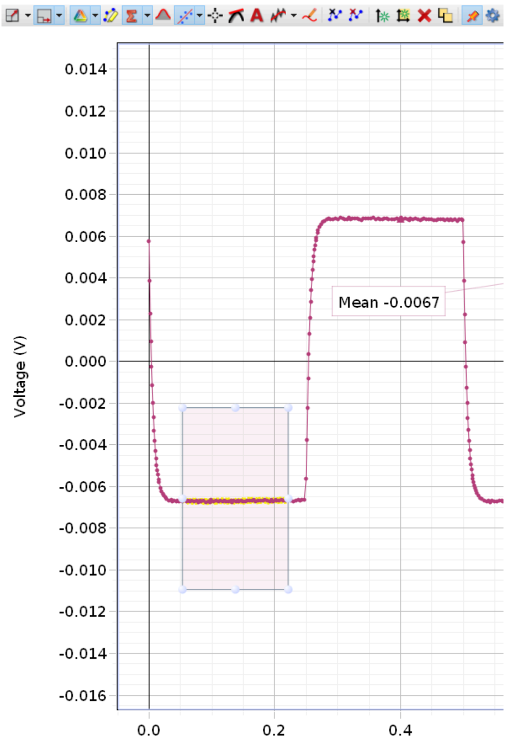
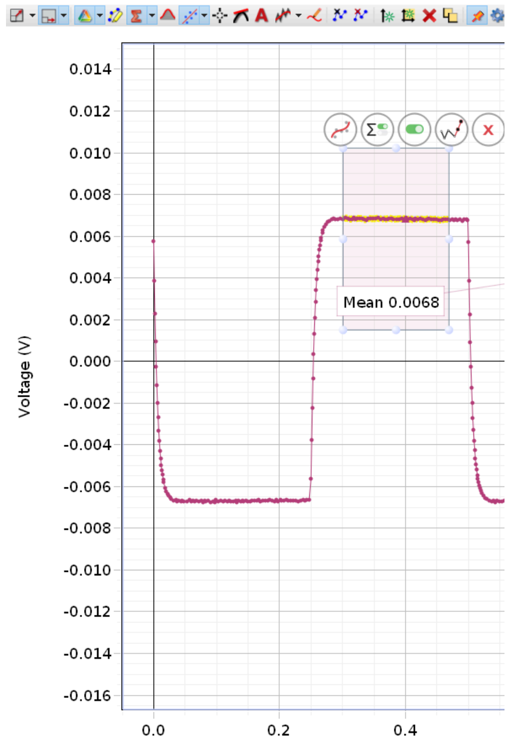


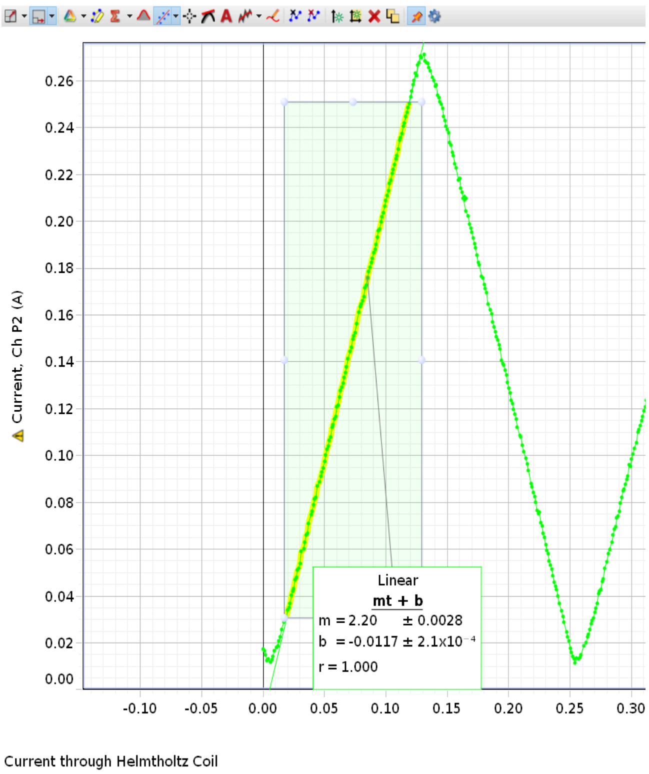
Electromotive Force (emf) from the induced coil

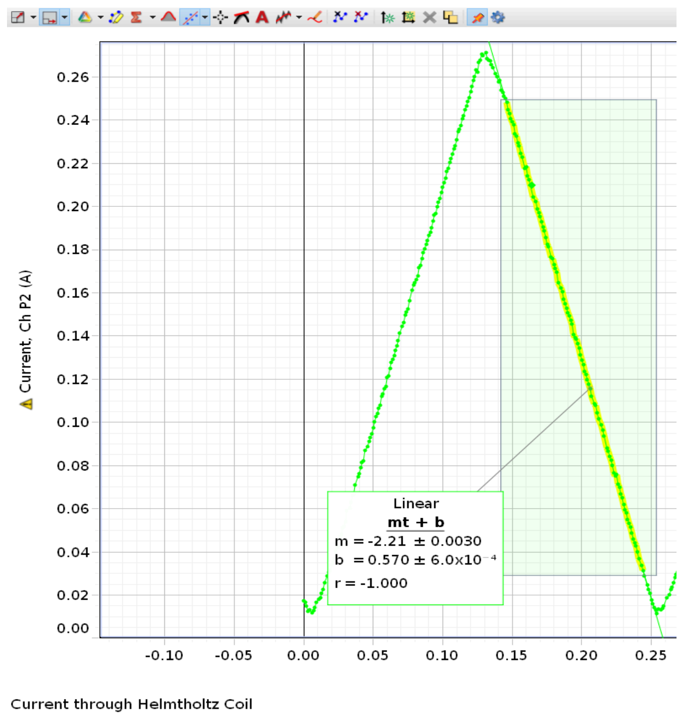


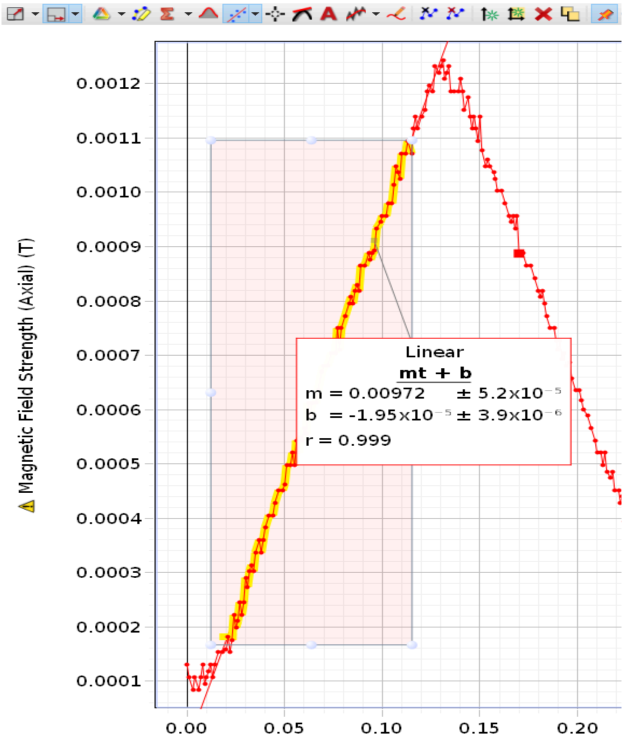
Electromotive Force (emf) from the induced coil

Frequency = 4Hz		**Current increase region**	**Current decrease region**
1	$\frac{dI(t)}{dt}$:Slope in current vs time graph [A/sec]	**2.20**	**-2.21**
2	emf: $\varepsilon = -\ 8.992x10^{-7}(NA)(\frac{N_b}{R})\frac{dI(t)}{dt}$ [V]	**-0.0120**	**-0.0121**
3	$\frac{dB(t)}{dt}$: Slope in Magnetic field strength vs time graph [T/sec]	**0.00972**	**-0.00943**
4	Emf: $\varepsilon = -\ NA\frac{dB(t)}{dt}$ [V]	**-0.0124**	**-0.0120**

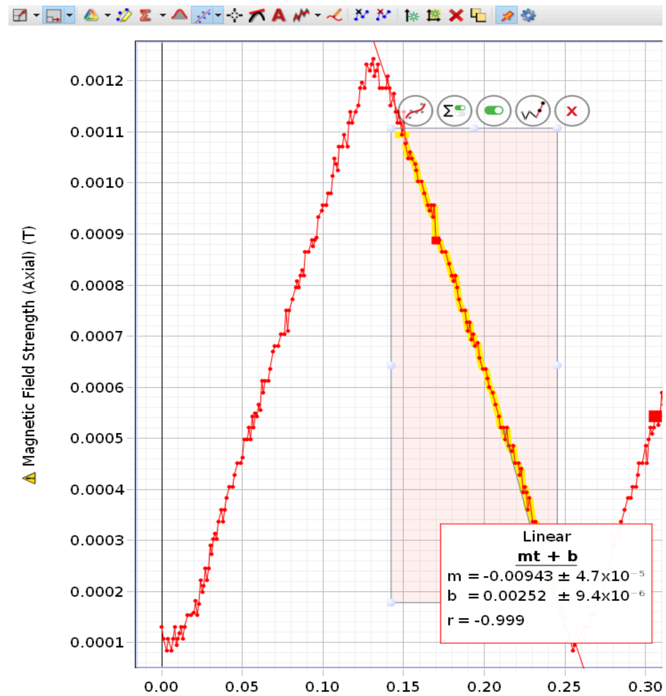
5	Experimentally Measured emf [V]	-0.0129	0.0146



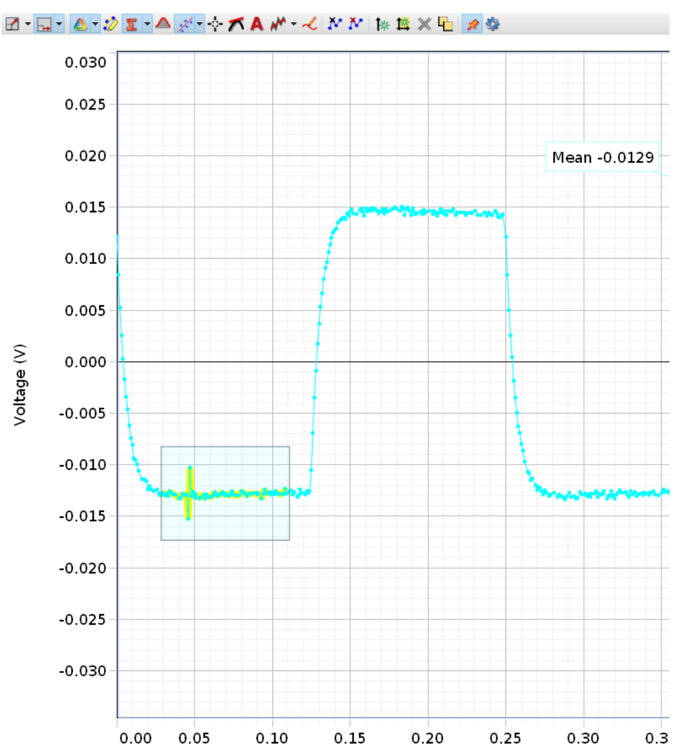




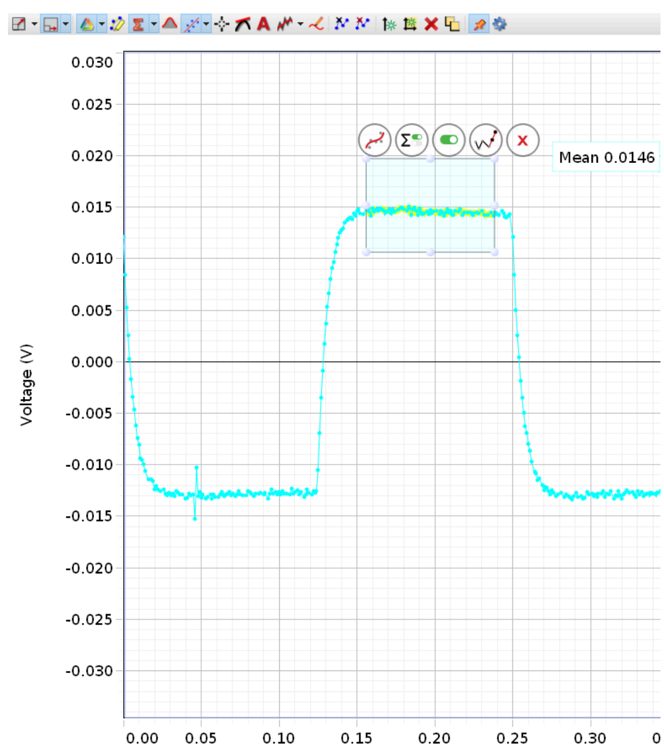
Magnetic Field Strength through Helmholtz Coils



Magnetic Field Strength through Helmholtz Coils



Electromotive Force (emf) from the induced coil



Electromotive Force (emf) from the induced coil

3.2 CALCULATION

$$A = \frac{\pi}{4}d^2 = \frac{\pi}{4}(28.5 \cdot 10^{-3} m)^2 = 6.379 \cdot 10^{-4} m^2$$

4. **ANALYSIS and DISCUSSION**

Faraday's Law says that the amount of the induced emf in a conductor is proportional to the rate of change of magnetic flux linkage. An emf is created in a conductor when the magnetic flux passing through it changes.

This experiment taught us more about Faraday's Law and how to show it using electromagnetic induction. I learnt that the emf has varying values depending on the Hz and magnet. The graph of induced EMF against time shows a linear connection, implying that the induced EMF is proportional to the rate of change of magnetic flux through the coil, as anticipated by Faraday's Law. As the magnet travels away from the coil, the magnetic flux across it diminishes, producing an induced EMF in the coil.

1- Compare the emf which you have calculated based on $\frac{dI(t)}{dt}$ and $\frac{dB(t)}{d(t)}$ with experimentally measured emf. What is the percentage error ?

We'll need to calculate the average of the dI(t)/dt and dB(t)/dt values. After analyzing everything, We discovered that the percentage difference between them is around 3.6-3.7%.

2- What if the small(induced)coil is at 45 degrees to the Helmholtz coils ? Does the induced emf increase or decrease ? Explain your answer.

When the tiny (induced) coil is positioned 45 degrees from the Helmholtz Coils, the induced emf decreases. The equation Φ=BAcos(θ) is used to calculate emf. If the angle turns to 45 degrees, the value of Φ decreases.

3- If the coils is at 45 degree we will have to multiply it by cos 45 meaning it will increase by $\sqrt{2/2}$?

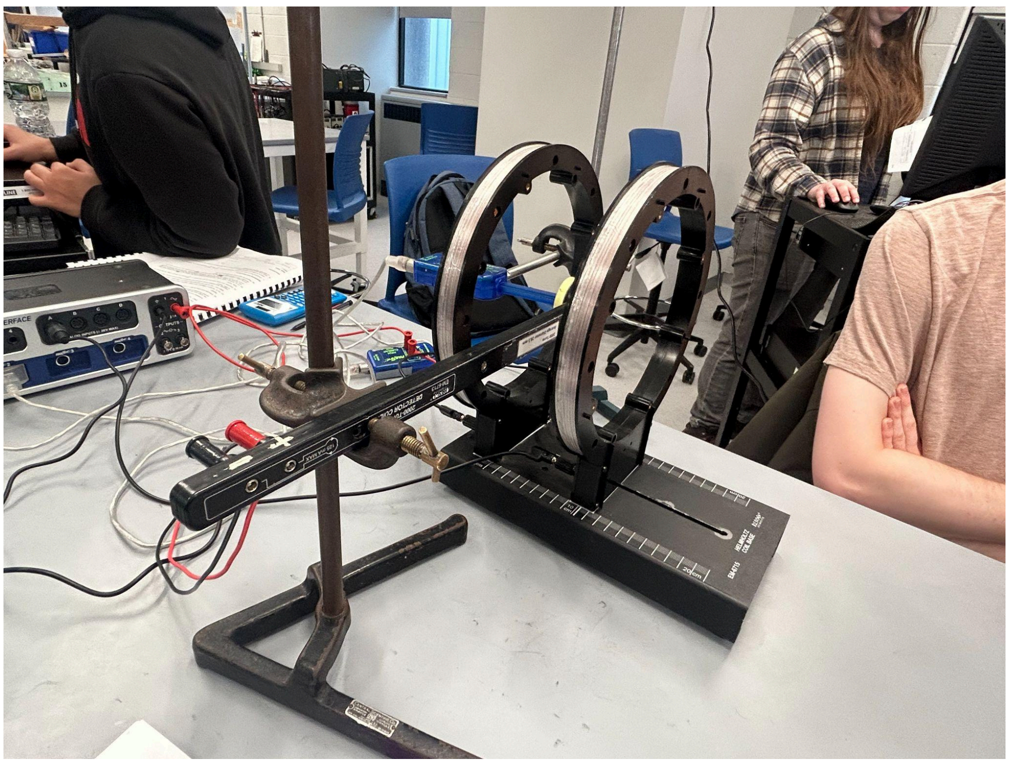
No, if you're talking about a coil that generates a magnetic field, multiplied by cos(45°) yields the component of the magnetic field that contributes to the desired effect in the direction of interest. It's similar to breaking down a vector into its constituent parts.

5. **CONCLUSIONS**

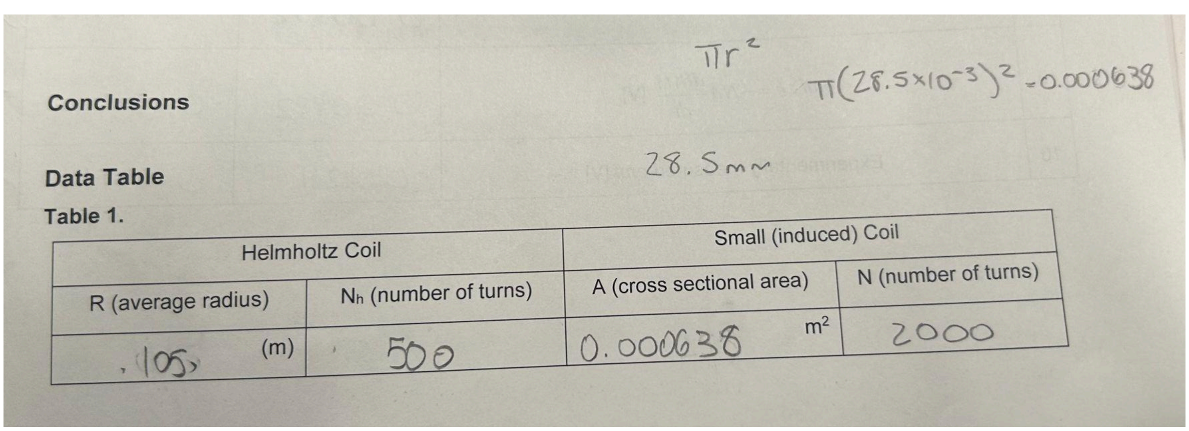
This experiment taught us more about Faraday's Law and how to show it using electromagnetic induction. I learnt that the emf has varying values depending on the Hz and magnet. It effectively established Faraday's Law of Electromagnetic Induction. The induced EMF in a coil is proportional to the rate at which magnetic flux passes through it. As the magnet moved away from the coil, the induced EMF grew linearly over time, proving Faraday's Law. After completing all of the tests, Faraday concluded that the existence of relative motion between a conductor and a magnetic field caused a change in the flux linkage with a coil, resulting in a voltage across the coil. Faraday's law states that an electromotive force is generated when a magnetic flux or magnetic field fluctuates over time. Michael Faraday also developed two laws based on his experiments. Throughout this experiment, I learned more about Faraday's Law and how to demonstrate electromagnetic induction. I observed that the emf values changed according to the magnet's Hz. After completing the lab we confirmed and used our physics knowledge in real life. We confirmed our knowledge of the previous labs.

6. **RAW DATA**

Part 1



Table



πr^2

$\pi(28.5\times10^{-3})^2 = 0.000638$

Conclusions

28.5mm

Data Table

Table 1.

Helmholtz Coil		Small (induced) Coil	
R (average radius)	N_h (number of turns)	A (cross sectional area)	N (number of turns)
.105 (m)	500	0.000638 m^2	2000

Table 2.

	Frequency = 2 Hz	Current increase region	Current decrease region
1	$\frac{dI(t)}{dt}$: Slope in current vs. time graph [A/sec]	1.21	-1.20
2	$emf: \varepsilon = -8.992\times10^{-7}(NA)(\frac{N_h}{R})\frac{dI(t)}{dt}$ [V]	-0.0210	-0.0121
3	$\frac{dB(t)}{dt}$: Slope in magnetic field strength vs. time graph [T/sec]	0.00442	-0.00444
4	$emf: \varepsilon = -NA\frac{dB(t)}{dt}$ [V]	-0.0123	0.0119
5	Experimentally measured *emf* [V]	-0.0067	0.0068

	Frequency = 4 Hz	Current Increase region	Current decrease region
6	$\frac{dI(t)}{dt}$: Slope in current vs. time graph [A/sec]	2.20	-2.21
7	$emf: \varepsilon = -8.992\times10^{-7}(NA)(\frac{N_h}{R})\frac{dI(t)}{dt}$ [V]	-0.0120	-0.0121
8	$\frac{dB(t)}{dt}$: Slope in magnetic field strength vs. time graph [T/sec]	0.00972	-0.00943
9	$emf: \varepsilon = -NA\frac{dB(t)}{dt}$ [V]	0.00972	-0.00943
10	Experimentally measured *emf* [V]	-0.0129	0.0146