PHYS 230
RE-DO LAB-2 REPORT

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Lab Date: 02.03.2025

INTRODUCTION

OBJECTIVE

This experiment investigates two key objectives:

1. Experimentally determine the charge-to-mass ratio e/m .

2. Calculate the Earth's magnetic field B_E and compare it to the accepted value of (4.8±0.3) ×10^{-5} T.

BACKGROUND THEORY

The charge-to-mass ratio of an electron (e/m) is a fundamental constant in physics, playing a crucial role in understanding electromagnetic interactions. Applications of this concept range from particle accelerators, such as the Large Hadron Collider, to electric motors and railguns. In this experiment, we determine the charge-to-mass ratio of the electron by analyzing its circular motion in a magnetic field and estimate the Earth's magnetic field.

EQUATIONS

Electrons are accelerated through a potential difference V, gaining kinetic energy:

$$\frac{1}{2}m_e v^2 = eV$$

where m_e is the mass of an electron, v is its velocity, and e is its charge. When moving perpendicularly to a magnetic field B, the Lorentz force causes the electrons to follow a circular trajectory:

$$\frac{m_e v^2}{r} = evB$$

Solving for e/m gives:

$$\frac{e}{m} = \frac{2V}{B^2 r^2}$$

The magnetic field in this experiment is produced by a Helmholtz coil, given by:

$$B_H = \frac{8\mu_0 NI}{\sqrt{125}R}$$

where N is the number of turns in the coil, R is the coil radius, I is the current, and μ_0 is the permeability of free space. Since the Earth's magnetic field B_E affects the experiment, the total field is adjusted to $B_H - B_E$, leading to:

$$\frac{e}{m} = \frac{2V}{(B_H - B_E)^2 r^2}$$

To linearize, we plot $\sqrt{2V} / r$ against I:

$$\frac{\sqrt{2V}}{r} = I \cdot \frac{\sqrt{125}R}{8\mu_0 N} \frac{1}{\sqrt{e / m}} - \frac{\sqrt{125}RB_E}{8\mu_0 N}$$

METHODS

EQUIPMENT USED

1. Red Lamp
2. Voltmeter
3. Helmholtz Coil & Electron Tube
4. Ammeter
5. DC Power Supply (15V to 45V)

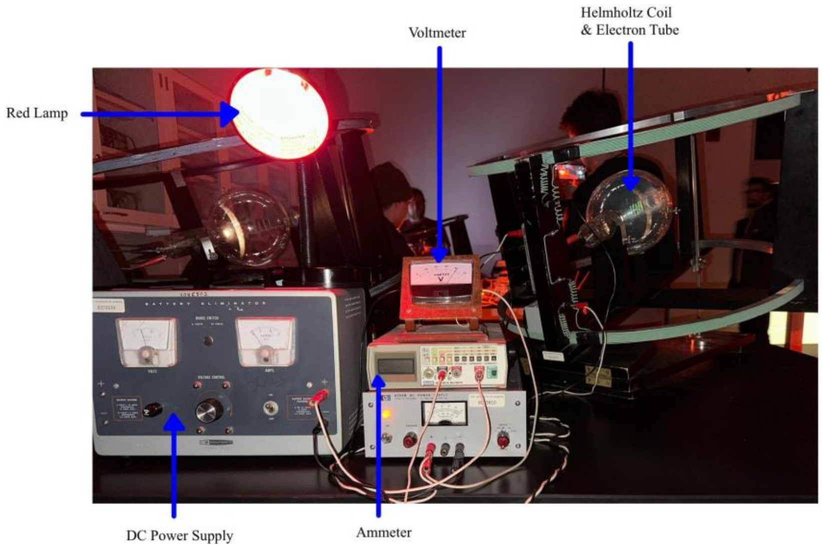


Fig 2.1: Labelled image of setup.

The Helmholtz coils were aligned anti-parallel to the Earth's magnetic field by tilting the apparatus 18° upward and orienting it so that the compass on the base pointed magnetic north. The electron beam, generated inside the evacuated tube, became visible as a faint blue ring when energized. The experiment involved adjusting the current until the beam aligned with known radii defined by phosphorescent pegs.

PROCEDURE

1. Ensure that the Helmholtz coils are aligned antiparallel to the Earth's magnetic field (In Edmonton, the field is tilted 72° to the horizontal). This alignment was pre-set in the lab.
2. Set up the experimental apparatus as shown in the lab manual. Turn off the main lights to improve visibility of the electron beam. Use a red light to illuminate the measuring equipment.
3. For accelerating voltages V = 20V, 30V, and 40V, adjust the current I in the Helmholtz coils until the electron beam aligns with the outer edge of each peg at radii r = 3.25, 3.90, 4.50, 5.15, and 5.75 cm.
4. Record the voltage V and the corresponding current I for each peg position.

RESULTS
RAW DATA

Table 2.1: Table showing the current required to bend the electron beam to the outer side of each peg. Full table can be found in Appendix under Table 2.2.

Voltages (V)	**Current (A)**				
	Peg 1	**Peg 2**	**Peg 3**	**Peg 4**	**Peg 5**
20	1.8	1.3	1.1	0.9	0.7
30	2.3	1.9	1.6	1.2	1.0
40	2.9	2.2	1.7	1.2	1.1

SAMPLE CALCULATIONS
For V = 30V, Peg 3, Current = 1.6A, N = 72 turns, r = 0.045m, R = 0.33m:

1. Computing B

$$B_H = \frac{8\mu_0 NI}{\sqrt{125}R} = \frac{8\,(4\pi * 10^{-7})(72)(1.6)}{\sqrt{125}(0.33)} = 3.14 * 10^{-4}T$$

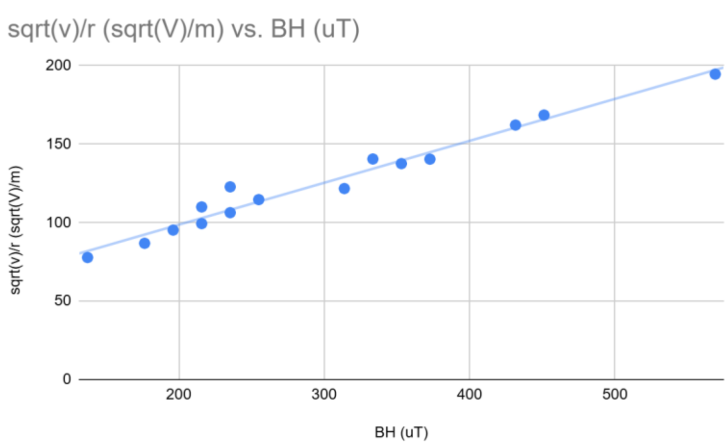
$$\sqrt{\left(\frac{\Delta I}{I}\right)^2 + \left(\frac{\Delta R}{R}\right)^2} = \sqrt{\left(\frac{0.01}{1.6}\right)^2 + \left(\frac{0.01}{0.33}\right)^2} = 0.03\text{ T}$$

2. Solving for e/m

$$\frac{e}{m} = \frac{2V}{(B_H - B_E)^2 r^2} = \frac{2(30)}{((3.14*10^{-4}) - (4.8*10^{-5}))^2 (0.045)^2} = 4.19 * 10^{11}\ C/Kg$$

GRAPH

Graph 2.1: Linear relationship between $\frac{\sqrt{2V}}{r}$ and B_H.



Slope = m_e= (0.267 ± 0.01) *10^{11} C/Kg
Intercept = B_E= (45 ± 4) * 10^{-5} T

This graph linearizes the experimental relationship based on the equation derived from the theoretical model $\frac{e}{m} = \frac{2V}{(B_H - B_E)^2 r^2}$
The slope of the line is used to calculate the charge-to-mass ratio of the electron, while the y-intercept corresponds to the Earth's magnetic field B_E. Data points were collected for voltages of 20 V, 30 V, and 40 V across five beam radii, and uncertainties were considered in both axes.

DISCUSSION

RESULTS AND COMPARISON

The experimentally determined charge-to-mass ratio of the electron was $4.19 * 10^{11}\ C/Kg$.This value is significantly larger than the accepted value of $4.19 * 10^{11}\ C/Kg$. The percentage error is approximately 138%, indicating that our result **does not agree** with the accepted value, even when accounting for uncertainty.

Similarly, the experimentally determined Earth's magnetic field was $4.19 * 10^{11}\ C/Kg$. The accepted value is (4.8±0.3) * 10^{-5} T. The experimental value is **over 8 times greater** and **outside of any overlapping uncertainty range**, confirming a **clear disagreement**.

DISCUSSION OF RESULTS

Although the plotted data followed a consistent linear trend, the large discrepancy between calculated and accepted values highlights substantial experimental error. This includes both systematic errors (e.g., poor alignment of coils or beam distortion) and random errors (e.g., flickering beam affecting radius readings).

The results suggest that while the procedure was executed consistently, the accuracy of the measurements was compromised. The misalignment likely exaggerated the actual magnetic field experienced by the electrons, leading to a significantly higher estimate of e/m and B_E.

The error in e/m further propagated into the calculation of $B_E$since the y-intercept of the linearized equation depends on it. This interdependence may have compounded the overall deviation.

UNCERTAINTIES AND IMPROVEMENTS

Uncertainties

1. Alignment Errors: If the Helmholtz coil was not perfectly aligned antiparallel to the Earth's magnetic field, the total magnetic field $B_H - B_E$ would be miscalculated, affecting the computed e/m ratio.
2. Measurement Uncertainties: The visibility of the electron beam was dependent on brightness and environmental lighting conditions, making precise measurements of beam radius challenging.
3. Systematic Errors: Fluctuations in current, minor variations in coil radius, or experimental imperfections in voltage settings may have led to deviations from the expected values.

Improvements

- Better Alignment: Ensuring precise positioning of the Helmholtz coils using a compass and level to minimize misalignment errors.

- Shielding from External Fields: Reducing interference from surrounding electromagnetic fields could improve accuracy in measuring B_E.

QUESTIONS

1. Why must the Helmholtz coil be aligned antiparallel to B_E?
    - Aligning B_H anti-parallel to B_E allows for direct subtraction of the magnetic fields in the same axis, simplifying the analysis. Misalignment would introduce vector components, requiring trigonometric corrections and increasing error.
2. What if the beam contained multiple ions of different masses?
    - Particles with different charge-to-mass ratios follow different-radius circular paths, resulting in multiple distinct rings instead of a single clear trajectory. This would prevent accurate determination of a single e/m value and would complicate data collection.

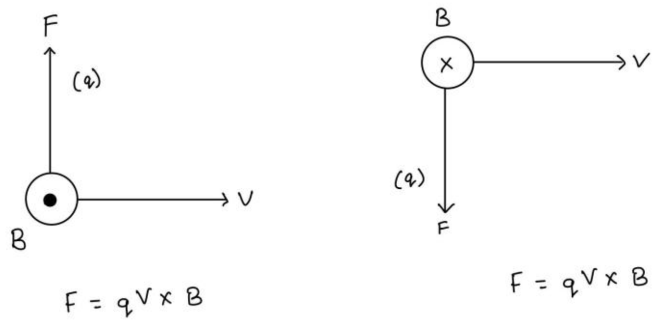


Fig 2.2: Shows directions of F, B, V, and q, and proves that formula F = qV x B is correct using the left-hand rule.

CONCLUSION

The experiment yielded an experimental charge-to-mass ratio of $4.19 * 10^{11}\ C/Kg$ and an Earth's magnetic field of (45 ± 4) * 10^{-5} T. These values significantly deviate from the accepted values of $1.76 * 10^{11}\ C/Kg$ and (4.8 ± 0.3) * 10^{-5} T, likely due to alignment, measurement errors, and limitations in precision equipment.

Despite these discrepancies, the experiment successfully demonstrated the fundamental relationship between electric and magnetic fields in charged particle motion. By accelerating electrons and analyzing their circular paths under magnetic influence, we were able to apply key physical laws to extract meaningful quantities. With improved alignment, digital instrumentation, and reduced external interference, future experiments could achieve values more consistent with theory.

REFERENCES

1. *PHYS 230 Lab Manual 2*, University of Alberta, 2025. [Online]. Available: eClass. [Accessed: Feb. 09, 2025].

ACKNOWLEDGEMENTS

I would like to thank my lab TA, Joshua Peltonen, for guiding me throughout the lab and explaining the concepts behind the experiment and ensuring my lab data was correct. I would also like to thank my lab partners, Muhammad Abdurrab Siddiqui,and Muhammad Ayaan Hafeez for helping me set up the experiment and for keeping the lab environment enjoyable.

APPENDIX

Table 2.2: Collected Raw Data with uncertainties.

Voltage V ± 0.05 (V)	Current I ± 0.05 (A)	Peg number	Radius r (m) ± 0.001	BH ±0.05 (μT)	sqrt(V)/r (sqrt(V)/m)	Diameter d ± 0.001 (m)
20	1.8	1	0.033	353.13	137.6041832	0.065
20	1.3	2	0.039	255.04	114.6701527	0.078
20	1.1	3	0.045	215.80	99.3807990	0.090
20	0.9	4	0.052	176.57	86.83759136	0.103
20	0.7	5	0.058	137.33	77.77627748	0.115
30	2.3	1	0.033	451.22	168.5300177	0.065
30	1.9	2	0.039	372.75	140.4416814	0.078
30	1.6	3	0.045	313.89	121.7161239	0.090
30	1.2	4	0.052	235.42	106.3538947	0.103
30	1.0	5	0.058	196.18	95.25609696	0.115
40	2.9	1	0.033	568.93	194.6017022	0.065
40	2.2	2	0.039	431.60	162.1680851	0.078
40	1.7	3	0.045	333.51	140.5456738	0.090
40	1.2	4	0.052	235.42	122.8068994	0.103
40	1.1	5	0.058	215.80	109.9922664	0.115