PHYS 230
LAB-2 REPORT

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INTRODUCTION

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.

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:

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

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

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

In this experiment, we aim to:

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 $(4.8 \pm 0.3) \times 10^{-5}$ T.

EQUIPMENT

1. Red Lamp
2. Voltmeter

3. Helmholtz Coil & Electron Tube
4. Ammeter
5. DC Power Supply (15V to 45V)

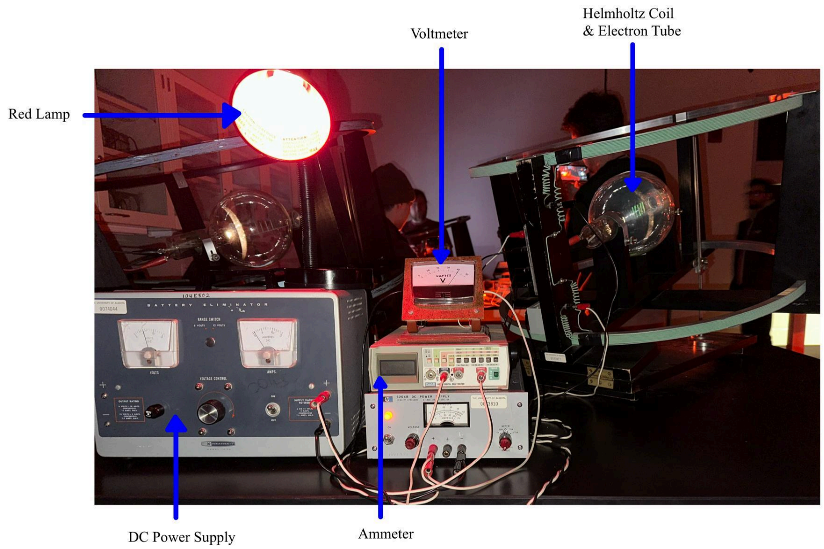


Fig 2.1: Labelled image of setup.

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

Table 2.1: Table showing the current required to bend the electron beam to the outer side of each peg.

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

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

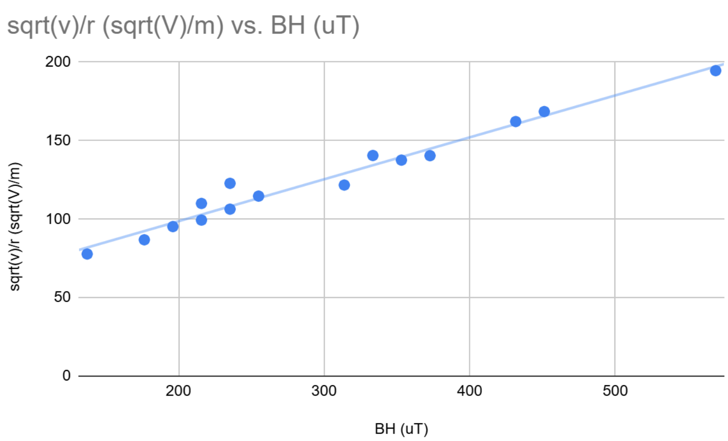
$$\sqrt{\left(\frac{\Delta I}{I}\right)^2 + \left(\frac{\Delta R}{R}\right)^2} = \sqrt{\left(\frac{0.01}{1.6}\right)^2 + \left(\frac{0.01}{0.33}\right)^2} = 0.03\ \mathrm{T}$$

2. Solving for e/m

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

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

DISCUSSION

Our experimentally determined value for the charge-to-mass ratio of the electron was $4.19 * 10^{11}\ C/Kg$. This deviates significantly from the accepted value of $1.76 * 10^{11}\ C/Kg$, indicating potential errors in measurement, alignment, or systematic inaccuracies.

Similarly, our experimental value for the Earth's magnetic field, determined from the intercept of the graph, was (45 ± 4) $* 10^{-5}$ T. This value is significantly larger than the accepted value of (4.8±0.3)$* 10^{-5}$ T, suggesting that external magnetic influences or misalignment of the Helmholtz coil may have affected the results.

Potential Sources of Error

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.

Addressing the following key questions:

1. Why must the Helmholtz coil be aligned antiparallel to B_E?
   - This ensures that B_H directly opposes B_E, simplifying calculations and reducing unwanted deviations.
2. What if the beam contained multiple ions of different masses?
   - Ions with different charge-to-mass ratios would follow different circular paths, leading to a spread in beam trajectories rather than a single defined orbit.

CONCLUSION

The experiment yielded an experimental charge-to-mass ratio of $4.19 * 10^{11}\ C/Kg$ and an Earth's magnetic field of $(45 \pm 4) * 10^{-5}$ T. These values significantly deviate from the accepted values, likely due to alignment and measurement errors. Despite these discrepancies, the experiment demonstrated the fundamental relationship between electric and magnetic fields in charged particle motion. By improving experimental precision and minimizing external interference, future results could achieve better agreement with theoretical expectations.

REFERENCES

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

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