PHY324 Charge To Mass Ratio Lab

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1 Abstract

This experiment is a variation of the original experiment carried out by J.J. Thompson in 1895 where the charge to mass ratio for an electron was measured. Using a 0 to 300 volt power supply and an electron gun, electrons were accelerated into Hg gas where they would be in a visible, circular orbit. It is in this setup where measurements took place. The charge to mass ratio was measured to be $1.1228x10^9 Wb/m$

2 Introduction

In this experiment, the deflection of a charge moving in a magnetic field was carried out. A particle of mass m and charge e moving in a magnetic field experiences a force given by:

$$F = ev \times B \tag{1}$$

where v is the velocity of the particle and B is the magnetic field experienced by the particle. For this lab, electrons were accelerated into a circular orbit by which they obeyed non-relativistic circular motion properties. Recall the net force of an object moving in a circular manner is given by:

$$F_c = m\frac{v^2}{r} \tag{2}$$

where r is the radius of the orbit. This can be set equal to the magnetic force experienced by the particle, since both are the net force on the particle:

$$evB = m\frac{v^2}{r} \tag{3}$$

In this experiment, the particle is accelerated through a potential difference, V. Note that the energy of the electron is given by eV, but is also in the form of kinetic energy as the particle moves with some velocity v. Thus, the two energies can be equated:

$$eV = \frac{1}{2}mv^2 \tag{4}$$

Note that from equation 3:

$$v^2 = \frac{evBr}{m} \tag{5}$$

and so, plugging this into the energy formula (equation 4) gives the radius of curvature for the electron:

$$r = \sqrt{\frac{2mV}{e}}\frac{1}{B} \tag{6}$$

3 Setup and Methods

Below is the setup for this experiment:

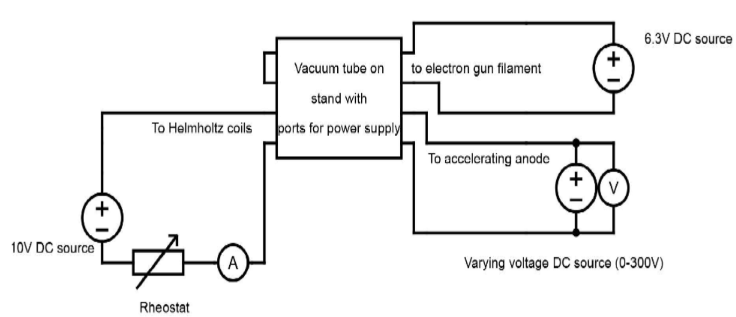

Figure 1: Circuit Setup

The main apparatus for this experiment is a glass bulb containing an electron gun and hydrogen gas. This bulb is connected to an anode which supplies the electron gun with electrons. This anode is connected in series to a 0 to 300 volt power supply. This power supply has a multimeter connected to it in parallel so that the voltage across it can be read. The bulb is also connected to the electron gun filament, which gets its power from a 6.3 volt power source connected in series with it. The current in the coils is supplied from an 8 volt DC power supply. This power supply is also connected in series with a rheostat and a multimeter that reads current. The rheostat is a device that controls the resistance of the current, and thus, this can be used to control the current going into the coils.

For this experiment, electrons were fired through a filament into the glass bulb filled with hydrogen gas. These electrons underwent circular motion due to the bulb being in between two conducting wired coils, which produced a magnetic field across the bulb. It is important to note that the bulb can rotate, and thus, it must be as straight as possible so that the circular motion of the electrons is purely 2-D vertically. Any tilt in the bulb will cause the electron to spiral, resulting in inaccurate measurements. Measurements of the radius of curvature were taken using an illuminated scale. To eliminate parallax in the illuminating scale, it was important to ensure that it was perfectly facing the beam of electrons. To do this, measurements of the distance between each side of the mirror and the coils were taken. Once these distances were found to be equal, it was known that the mirror was face-on with the beam of electrons. It was also important to not have any external ferromagnetic materials around, or else this would affect the beam's trajectory. For example, putting a cellphone near the bulb decreased the radius of curvature as is repelled electrons.

4 Results

For this experiment, the following radius equation was rearranged for B_c:

$$1/r = \sqrt{\frac{e}{2mV}}(B_c + B_e) \tag{7}$$

This gave an equation of the form:

$$B_c = \sqrt{\frac{m}{e}}\frac{\sqrt{2V}}{r} - B_e \tag{8}$$

By plotting B_c against $\frac{1}{r}$, the magnetic field of the Earth could be found by finding the y-intercept of the equation above, and the charge to mass ratio can be found by finding the slope of the equation above and rearranging it. Since the slope is given by:

$$slope = \sqrt{\frac{m}{e}} \tag{9}$$

and so the charge to mass ratio must be:

$$\frac{e}{m} = \frac{1}{slope^2} \tag{10}$$

For this particular experiment, three voltages were analyzed, each at 5 different currents. The radius was measured at each of the measured currents, and then plotted against B_c in figure 2 below:

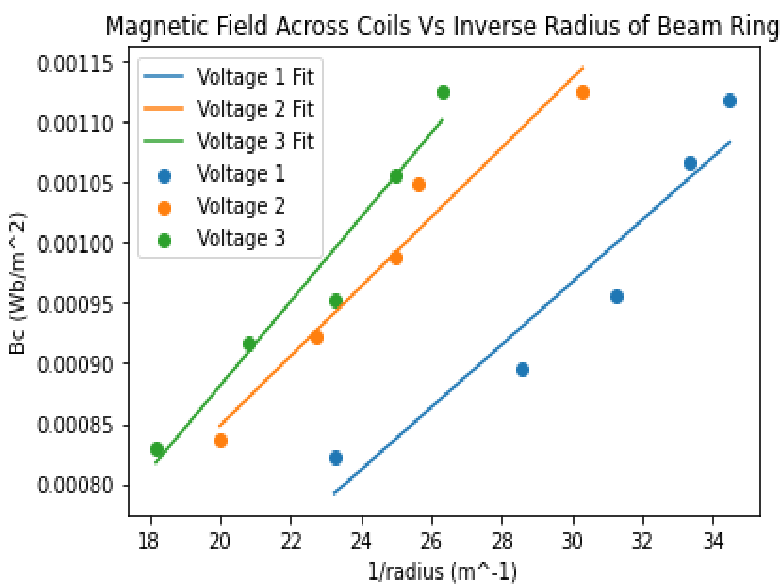

Figure 2: Bc vs 1/r Plot

Using the curvefit function in Scipy, the optimal slopes of each line were found. The average of these slopes were taken and that was used to find the charge to mass ratio of $1.1228x10^9 Wb/m$ and the optimal y-intercepts were found and averaged to get the magnetic field of the earth, $2.1558x10^{-4} Wb/m^2$.

Notice that the Earth's magnetic field can also be calculated using the following equation:

$$\frac{1}{r} = \sqrt{\frac{e}{2mV}}((\frac{4}{5})^{\frac{3}{2}}\frac{\mu_0 nI}{R} + B_e) \tag{11}$$

5 Discussion

According to external literature cited in the references section, the magnetic field of the earth is about $3x10^{-5}Wb/m^2$ and the charge to mass ratio of an electron is, $1.76x10^{11}C/kg$ therefore my values were off. This could be due to some error in my measurements. For example, the beam of electrons was very dim, and thus the ring could not be seen very well, causing me to have inaccurate measurements in the radius.

The anomalous behaviour of the electron trajectory in the case of low accelerating voltage and high current in the coils shows the electrons hitting the glass bulb instead of oscillating in a circular orbit. It is important that this does not happen in the experiment as we only want forces from the magnetic field and not from electrons bouncing off the glass bulb.

6 Conclusion

To summarize, the charge to mass ratio of an electron was found to be $1.1228x10^9Wb/m$ and the magnetic field of the earth was found to be $2.1558x10^{-4}Wb/m^2$.

7 References

- PHY324 'Charge-To-Mass Ratio For The Electron' Lab Document
- https://www.vedantu.com/chemistry/charge-to-mass-ratio
- https://explainingscience.org/2016/04/24/the-earths-magnetic-field/

8 Appendix

The following is the collected data:

Voltage (V)	Current (A)	Radius (m)
166.437 +/- 0.001	1.230 +/- 0.001	0.043 +/- 0.001
	1.340 +/- 0.001	0.035 +/- 0.001
	1.432 +/- 0.001	0.032 +/- 0.001
	1.600 +/- 0.001	0.030 +/- 0.001
	1.675 +/- 0.001	0.029 +/- 0.001
218.287 +/- 0.001	1.250 +/- 0.001	0.050 +/- 0.001
	1.380 +/- 0.001	0.044 +/- 0.001
	1.480 +/- 0.001	0.040 +/- 0.001
	1.571 +/- 0.001	0.039 +/- 0.001
	1.686 +/- 0.001	0.033 +/- 0.001
241.277 +/- 0.001	1.241 +/- 0.001	0.055 +/- 0.001
	1.373 +/- 0.001	0.048 +/- 0.001
	1.425 +/- 0.001	0.043 +/- 0.001
	1.579 +/- 0.001	0.040 +/- 0.001
	1.686 +/- 0.001	0.038 +/- 0.001

Table 1: Resistance 1 for each device