Modern Physics Lab

Charge to Mass Ratio of the Electron

Purpose of the experiment

- Familiarize you with advanced experimental techniques and equipment.
- Determine the charge to mass ratio of an electron using a magnetic field.

Background Info

This goal of this experiment is to determine the charge to mass ratio (e/m) of the electron by analyzing the motion of an electron beam in a magnetic field. By using this method, it is not possible to determine either the charge or the mass independently. To accomplish that task, another experiment would need to determine one of these two constants. (See the Milliken Oil Drop Experiment to determine the charge of the electron.)

As found in the prelab, the charge to mass ratio as derived from Newton's Laws and Conservation of Energy is given by:

$$\frac{e}{m} = \frac{2V}{r^2 B^2} \quad \text{(Equation 1)}$$

where the magnetic field B is found from the Biot-Savart Law to be:

$$B = \frac{8\mu_O NI}{\sqrt{125}R} \quad \text{(Equation 2)}$$

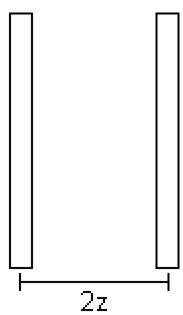
Prelab

- An electron is accelerated in an electron gun from rest through a potential difference of V. What is the final speed of the electron as it leaves the gun? Leave your answer in terms of the charge of the electron e, the mass of the electron m, and the accelerating potential difference V.

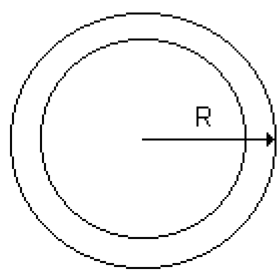
- Consider an electron moving in a uniform magnetic field of magnitude B. The electron's initial velocity is perpendicular to the magnetic field and its speed is given by the answer to the previous question. Find the ratio e/m for the electron in this system in terms of the potential difference V, the radius of the motion r, and the magnetic field B.

- In this experiment, a pair of Helmholtz coils will be used to generate a magnetic field. Using the Biot-Savart Law, calculate the magnetic field due to a ring of current I and radius R. To simplify your calculation, find the field only along the axis of symmetry, taking your field point to be at a distance z from the center of the ring.

- There are two identical Helmholtz coils in this experiment that have N identical rings each. The coils are parallel to each other and separated from each other by a distance of 2z. The same current flows in the same direction in each coil.



End View



Side View

Using your result from the previous question and the fact that R = 2z, show that the magnetic field due to the Helmholtz coils is:

$$B = \frac{8\mu_O NI}{\sqrt{125}R}$$

- You must also consider how to deal with the Earth's magnetic field. First, describe the conditions under which you may ignore the Earth's field. Then, describe what you must do if you can not ignore the Earth's field. Notice that N = 130, I = 1 A (approximately), and R = 150 mm.

- Find expressions for both the uncertainty in e/m and the uncertainty in B. Start from Equations 1 and 2.

Set Up

- Before starting, make sure all power supplies are off, and all current and voltage knobs are set to zero.
- Using the compass, align the Helmholz coils such that the Earth's magnetic field threads the coils. Be sure that you hook up your Helmholz coil circuit such that the field generated is parallel to the Earth's field. Also, with the compass, be sure that the surface you are working on is non-magnetic.
- With the equipment provided, set up the two circuits below. DO NOT turn on the power until your instructor has checked the circuits or you may burn out the equipment.

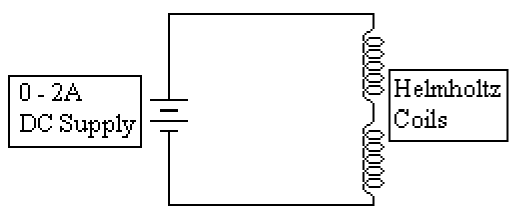


Figure 1: Helmholz coil circuit for generating the magnetic field.

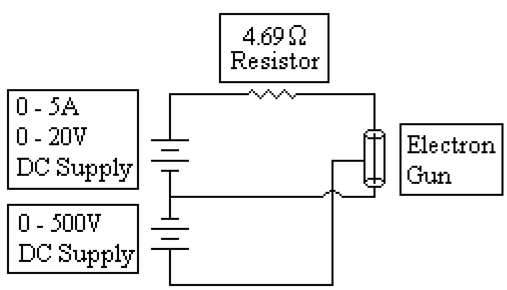


Figure 2: Power for electron gun.

- Now, insert an ammeter to measure the current in the coils and a voltmeter to measure the accelerating potential.
- Once your instructor has approved your set up, turn out the lights so you will be able to see the dim electron beam when it comes on.

- Using the 0 – 500V DC supply, apply about 40 V of accelerating potential to the electron gun. This potential will be used to accelerate the electrons.

- Slowly apply current to the electron gun filament using the 0–5A, 0–20 V DC supply. Starting with 1 A, slowly turn up the voltage to 4 A over 2 minutes. This will heat the filament and boil off electrons by thermionic emission. (See the Thermionic Emission Lab.) DO NOT exceed 4.5 A, or you may burn out the filament.

    - At a little over 2 A, you should see a dim orange glow in the electron gun as the filament starts to warm up.

    - Within a minute or two of reaching 4 A, you should see a faint blue beam of electrons coming out of the top of the gun.

    - For best results, keep the filament current as low as possible while still producing a visible beam.

- Turn up the accelerating potential to 150 V using the 0 – 500V DC supply.

- Apply a magnetic field to the system by putting a current through the Helmholz coils with the 0 – 2A DC supply. DO NOT exceed 2 A. The electron beam will curl in response to the magnetic field. You are now ready to begin the lab.

The Lab

The goal: To measure the charge to mass ratio of the electron using a magnetic field.

Remember to include the uncertainty in your measurement and the units

Data Collection

Consider the following when performing this experiment:

- The apparatus has five pins inside the bulb. The distances from the filament to the farthest edge of the pins are:

  Pin 1: 0.065 m
  Pin 2: 0.078 m
  Pin 3: 0.090 m
  Pin 4: 0.103 m
  Pin 5: 0.115 m

  All values have an uncertainty of 0.001 m.

- If the beam does not strike the pins, the tube may need to be rotated in the holder. Ask your instructor for assistance in doing this.

- The Helmholz coils have the following properties:

  130 turns on each coil
  0.150 m average coil radius
  0.150 m separation between the two coils

- Which power supply controls the current (I) in Equation 2? How do you measure the current?

- Which power supply controls the accelerating voltage (V) in Equation 1? How do you measure the voltage?

- How many measurements of e/m can you make?

- Don't forget Earth's magnetic field.

- You will need to calculate an average and standard deviation for your measurements of e/m. Then, compare your average to the accepted value. Don't forget propagation of error through your calculations!

Shut Down

- Turn off the 0 – 2A DC supply for the Helmholz coils.
- Slowly turn down the 0 – 5A, 0 – 20V DC supply for the filament over 2 minutes.
- Turn off the 0 – 500V DC supply for the accelerating voltage.
- Take apart your circuits.
- [FYI]

[FYI] Your stomach has to produce a new layer of mucus every two weeks. Otherwise, it will digest itself.