Chapter 8

Lab 2: Measuring Electron Charge-to-Mass Ratio *e/m*

8.1 Purpose

- To determine the ratio of charge to mass for electrons.
- To calculate the earth's magnetic field.

8.2 Introduction

In this experiment, electrons emitted from a hot filament are accelerated by an electric field and then deflected by a magnetic field into a circular orbit. By measuring the accelerating potential of the electric field, the intensity of the magnetic field and the radius of the orbit, it is possible compute both the velocity of the electrons, and the ratio of charge to mass for the electrons. It is also possible to determine an approximate value of the earth's magnetic field.

When a stream of electrons has been accelerated through a potential difference V, the maximum kinetic energy per electron is given

$$\frac{1}{2}mv^2 = eV \tag{8.1}$$

where m is the mass of the electron, v is the final velocity of the electrons, and e is the charge of the electron. When a particle carrying a charge q moves with velocity $\mathbf{v}$ in a magnetic field $\mathbf{B}$, it is acted upon by the Lorentz force $\mathbf{F}$ given by

$$\mathbf{F} = q\mathbf{v} \times \mathbf{B} \tag{8.2}$$

If $\mathbf{B}$ and $\mathbf{v}$ are at right angles, the magnitude of the force is $F = qvB$ and the particle moves in a circular path, which is perpendicular to the magnetic field. The radius of this circle is such that the required centripetal acceleration is furnished by the Lorentz force. For the electrons in the present experiment, it follows that

$$\frac{mv^2}{r} = evB \tag{8.3}$$

where r is the radius of the circular path.

Substituting for electron velocity v from Equation 1 into Equation 3, we obtain an expression for the ratio of charge to mass

$$\frac{e}{m} = \frac{2V}{B^2 r^2} \tag{8.4}$$

In this experiment, the magnetic field is produced by a current in the Helmholtz coil. The magnitude of the magnetic field B_H for the region inside the coils is fairly uniform and is given by the equation:

$$B_H = \frac{8\mu_0 NI}{\sqrt{125}R} \tag{8.5}$$

where N is the number of turns in each coil, R is the radius of the coil, I is the current through the wire, and $\mu_0 = 4\pi \times 10^{-7}$ T m/A is the permeability of free space.

The earth's magnetic field is strong enough to cause an appreciable deflection of the electron beam. Therefore, it is necessary to account for the effect of the Earth's field $\mathbf{B_E}$ on the path of the electrons. One method is to align the apparatus so that the variable Helmholtz field is anti-parallel to the Earth's field. When a current is passed through the Helmholtz coil as shown in Figure 1, the magnetic field produced is anti-parallel to the earth's field. The total magnetic field present along the vertical axis of the Helmholtz coil is $(B_H - B_E)$. Therefore Equation 4 can be written as

$$\frac{e}{m} = \frac{2V}{(B_H - B_E)^2 r^2} \tag{8.6}$$

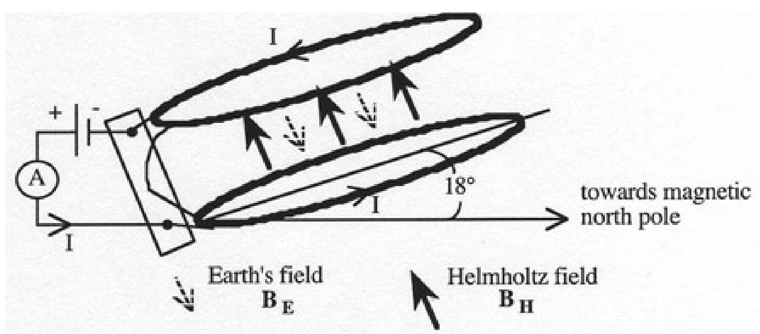

Figure 8.1: Alignment of Helmholtz coil opposite to earth's magnetic field.

In Edmonton, the earth's magnetic field points downward making an angle of approximately 72° with the horizontal. Therefore, to account for the earth's field, the Helmholtz apparatus should be orientated so that the compass on the base points to magnetic north, and the plane of the Helmholtz coil should be tilted upward at an angle of 18° relative to the horizontal.

8.3 Lab setup and procedure

1. The e/m apparatus involves three separate electrical circuits: filament circuit, anode circuit and Helmholtz circuit (Figure 2). Do not unplug any of the connectors. The filament should produce a white glow. As a voltage is increased beyond 12 V, a faint bluish beam is observed. This glow is produced by mercury vapor inside the tube being excited by collisions with electrons. As the current is increased, the beam should curve in a tighter circle towards the crossbar containing phosphorescent pegs.

2. For three selected voltages V between 15 V and 45 V, measure the Helmholtz current I required to align the beam with the far side of each peg. It is best to view the beam from overhead with brightness control adjusted for optimum sharpness. Record V and I measurements.

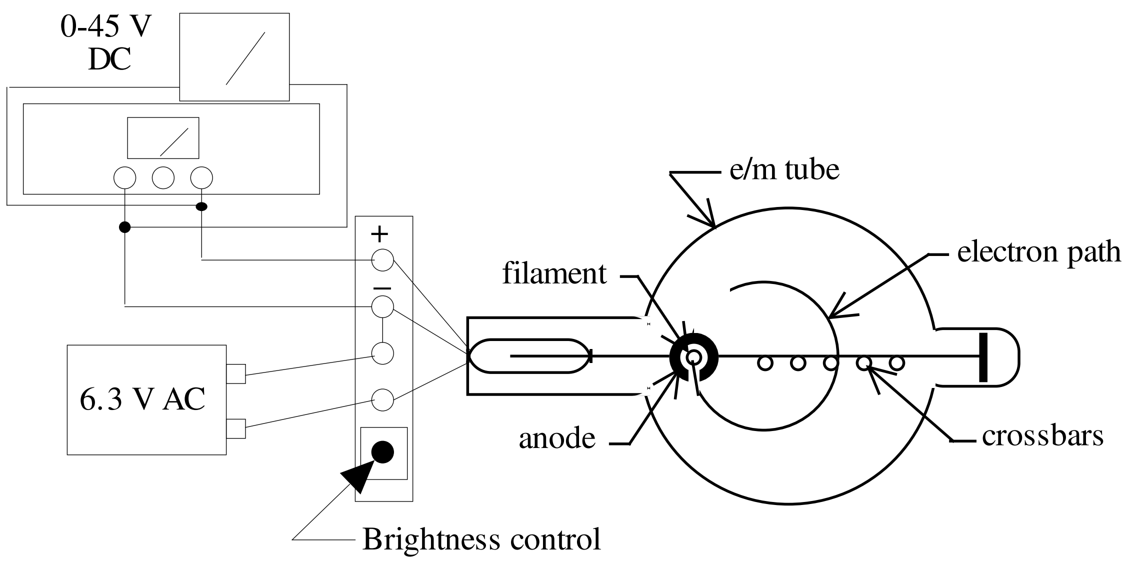

Figure 8.2: Experimental setup.

The number of turns in the Helmholtz coil is N = 72 and the radius R = 0.33 m. The distances to the outside of each peg (i.e. the *diameters* of the electron orbit) are 6.5, 7.8, 9.0, 10.3, and 11.5 cm.

8.4 Assignment

In this lab submission you will submit a full lab report (4 pages maximum). Handwritten work or images of handwritten work will not be accepted (except for the sketch). In preparing your full lab report, a full presentation of your results should include the following:

- Examine the directions of $\mathbf{v}, \mathbf{B}, \mathbf{F}$. Draw a sketch with vectors to show if the direction of the Lorentz force for an electron is correctly given by $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$. Use $\odot$ to indicate ”up” and $\otimes$ to indicate ”down”. This is the only part of the report that may be hand-written/hand-drawn.
- Derive Equation 6 and linearize it to determine a value for e/m and B_E from the slope and y-intercept of a straight-line graph. Compare your value of e/m to the accepted value of $1.76 \times 10^{11}\mathrm{C/kg}$, and your value of B_E to the value of $(4.8 \pm 0.3) \times 10^{-5}\mathrm{T}$.
- Why is it important to align the Helmholtz coil, so that its field is anti-parallel to the earth's magnetic field ?
- Explain what would happen if the beam in this experiment contained several ions of different masses.