Physics 121 Lab 8: MAGNETIC FORCES ON AN ELECTRON BEAM

1. Introduction

Today's experiment is designed to determine the experimental form of the magnetic force law. In order to determine the experimental form of the magnetic force law, we will take a beam of charged particles (electrons) and pass the beam through a magnetic field $\vec{B}$ perpendicular to the velocity $\vec{v}$ of the beam. By changing the accelerating potential difference that the electrons are accelerated through we can control the velocity of the charges and, for a fixed value of the magnetic field, determine the relationship between the magnetic force and the velocity of the electrons. Then by changing the current in a set of Helmholtz coils we can determine the relationship between the magnetic force and the magnetic field through which the electrons pass, for a constant value of velocity of the electron. In addition, we will determine two values for the charge-to-mass ratio *e/m* for the electron.

2. Apparatus

The apparatus consists of a special vacuum tube designed for this experiment and a set of Helmholtz coils to produce the magnetic field. Three power supplies are used to produce the magnetic field, the filament current that heats the wire, the source of electrons, and the accelerating voltage that defines the energy of the electrons. The beam of electrons is produced by an electron gun composed of a heater that heats a cathode electrode, which emits electrons. See Figure 1 for a photograph of the apparatus without the power supplies attached.

Figure 1: Photograph of the apparatus. The Helmholtz coils generate a uniform magnetic field that the electron beam passes through.

The kinetic energy gained by an electron is equal to the electric potential energy lost in traveling through a potential difference V. We can write this as

$$W = \Delta K \rightarrow -q\Delta V = eV = \frac{1}{2}mv^2 \qquad (1)$$

where we assume that the electron starts approximately from rest. From equation (1) we can determine the speed of the electrons as they emerge from the electron gun. The beam is made visible by the addition of a little inert neon gas in the tube; some of it evaporates in the tube and glows when electrons strike it. The path of the electron beam becomes circular when a magnetic field is applied, and the components are shown in Figure 2.

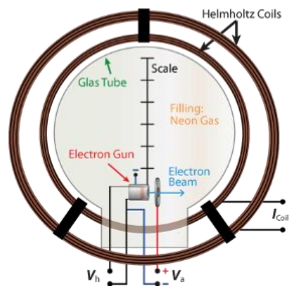

Figure 2: Schematic of the assembly showing the electron guns and the pins used to measure the electron beam radius. Photo: https://virtuelle-experimente.de/en/b-feld/b-feld/versuchsaufbau.php

A pair of Helmholtz Coils produces the magnetic field B. The magnitude of the B-field is expressed in terms of the current I through the Helmholtz coils and certain constants of the coil. We have the magnetic field given by

$$B = \frac{8\mu_0 NI}{\sqrt{125}a} \qquad (2)$$

where, N $(= 130)$ is the number of turns of the wire in each coil, I is the current through the coils, in Amps, a $(= 0.15m)$ is the mean radius of the coils (you should check this), and $\mu_0$is the permeability of empty space, $\mu_0 = 4\pi \times 10^{-7}\frac{Tm}{A}$. The radius of the circle is such that the required centripetal force is furnished by the magnetic force. Therefore, we have

$$F = qvB = ma_c = m\frac{v^2}{R} \qquad (3)$$

Substitution of equations (1) and (2) into equation (3) yields

$$R^2 = \left(\frac{250ma^2}{64\mu_0^2 N^2 e}\right)\frac{V}{I^2} \qquad (4)$$

3. The magnetic force versus velocity experiment:

- Your circuit is prewired, and you should neither take the wires out of their connections nor unplug any wires while the apparatus in on.
- Choose a constant value for the current in the Helmholtz coils and record this value.
- Vary the value of the accelerating potential difference (do not exceed 300V for long periods of time on the tube) until your electron beam passes between each set of pins. You may not be able to get the smallest set of pins. Don't worry if you cannot. Record the value of the electron beam radius and the accelerating potential difference in a table.

- Using equation 4, plot R versus V and determine the experimental relationship between R and V. Record your experimental expression. What should the experimental form be for the relationship between R and V? Is it as you expect?
- From this plot of R and V, how does the velocity of the charges relate to the magnetic force for a constant magnetic field B?
- Determine a value for the charge-to-mass ratio of the electron.

4. The magnetic force versus magnetic field experiment:

- Choose a constant value for the accelerating potential difference (preferably one that you've already done) and record this value.
- Vary the value of the current through the Helmholtz coils (do notexceed 2A for long periods of time on the coils) until your electron beam passes between each set of pins. Again, you may not be able to get the smallest set of pins. Record the value of the electron beam radius and the current in a table.
- Using equation 4, plot R versus I and determine the experimental relationship between R and I. Record your experimental expression. What should the experimental form be for the relationship between R and I? Is it as you expect?
- From this plot of R and I, how does the magnetic field relate to the magnetic force for a constant value of the velocity of the electrons?
- Determine a second value for the charge-to-mass ratio of the electron.