Physics 111

Laboratory #4

Magnetic Field of the Earth and Magnetic Force on an Electron Beam

1. Introduction

Today's experiment is designed to investigate the horizontal component of the Earth and to determine the experimental form of the magnetic force law. To determine the horizontal component of the Earth's magnetic field B_{Earth}, we will compare the unknown $B_{Earth}$with another magnetic field $\vec{B}$ whose strength is known. 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 themagnetic 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 intraveling 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 candetermine 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.

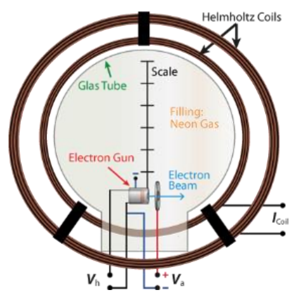

Figure 2: Schematic of the assembly showing the electron guns and the pins used to measure the electron beam radius. Photo: https://virtuelle-experimente.de/en/b-feld/b-feld/versuchsaufbau.php

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 thecoil. 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 horizontal component of the Earth's magnetic field experiment:

- Your circuit is mostly prewired, and you should neither take the wires out of their connections nor unplug any wires while the apparatus powered up.
- Because the magnetic field at your lab station is mainly from the earth, you should expect that a compass needle points roughly north. Check that it does so.
- Place the compass carefully at the center of the wire loop and align the coils so that the coils point north.
- The digital multi-meter in the circuit is set to read current in mA and the 220 Ohm resistor in the circuit is intended to prevent the current from getting too large and burning out the fuse of the multi-meter. Try running a current through the circuit to see that the compass needle does indeed deflect and in what direction.
- Now do things more carefully. Turn on the power supply and set the current so that the compass deflects through 40^0 and record the current.
- Turn off the power supply and reverse the leads going to the coils from the battery. Now repeat the step above and note that the compass deflects in the other direction.
- Repeat the previous two steps above for angles of 10, 20, 30, 50 and 60 degrees.
- Determine B, from equation 2 and plot B versus $\tan\theta$. Determine the value for the horizontal component of the Earth's magnetic field, B_{Earth}, from the plot.

4. The magnetic force versus velocity experiment:

- Your circuit is mostly prewired, and you should neither take the wires out of their connections nor unplug any wires while the apparatus is powered up.
- 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.

5. 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?