# MAGNETIC FORCES ON AN ELECTRON BEAM

1. Introduction

Today's experiment is designed to determine the functional form of the magnetic force law. velocity To determine the functional form of the magnetic force law, we will take a beam of charged particles (electrons) and pass the beam through a magnetic field **B** perpendicular to the velocity **v** of the beam. By changing the 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 schematic diagram of the apparatus.
The kinetic energy gained by an electron is equal to the electric potential energy lost in traveling through a potential difference V.

Figure 1 The e/m Apparatus
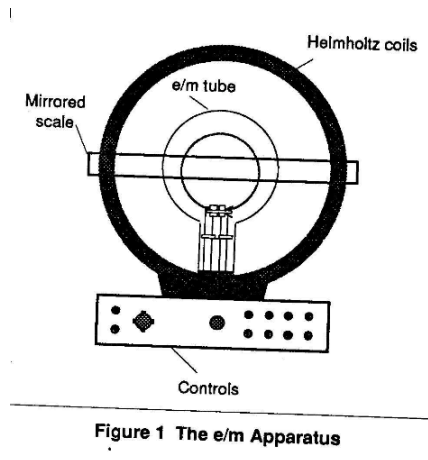
We can write this as

$$W = -q\Delta V = -(-e)[V - 0] = eV = \Delta KE = \frac{1}{2}mv^2 \quad (1),$$

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 helium 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 as shown in figure 2.
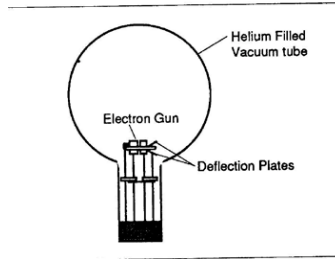
Figure 2 e/m Tube

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 coil, m0 is the permeability of empty space, which is $4\pi \times 10^{-7} \frac{T \cdot m}{A}$. The radius of the circle is such that the required centripetal force is furnished by the magnetic force. Therefore we have

$$F_B = qvB = F_C = \frac{mv^2}{R} \qquad (3)$$

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:

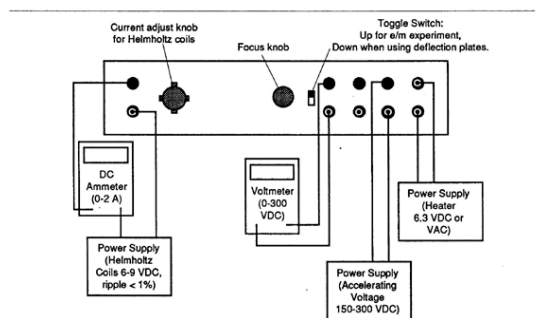- Make sure your circuit is wired as shown in figure 3 below.

Figure 3: Wiring diagram.

- Choose a constant value for the current in the Helmholtz coils and record this value.
- Choose 6 different values of the accelerating potential difference (do not exceed 300V on the tube) and record these in a table.
- For each of these 6 values of the accelerating potential differences record the radius of the electron beam in your table.

- Using equation 4, plot R versus V and determine the functional relationship between R and V. Record your expression for the functional form. What should the functional form be for the relationship between R and V? Is it as you expect?
- From this plot of R versus 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) record this value.
- Choose 6 different values of the current through the Helmholtz coils (do not exceed 2A on the coils) and record these in a table.
- For each of these 6 values of the current through the Helmholtz coils record the radius of the electron beam in your table.
- Using equation 4, plot R versus $\frac{1}{I}$ and determine the functional relationship between R and $\frac{1}{I}$. Record your expression for the functional form. What should the functional form be for the relationship between R and $\frac{1}{I}$? Is it as you expect?
- From this plot of R versus $\frac{1}{I}$, 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.