e/m experiment

Objective: To experimentally determine an electron's charge to mass ratio (e/m).

Introduction:

To meet this objective we will use a vacuum tube capable of producing a visible beam of electrons (The beam is visible because it excites the low-pressure gas contained in the tube.) When the beam is immersed in a magnetic field perpendicular to the beam direction, the negatively charged electrons will be deflected according to the magnetic force,

$$\overrightarrow{F_B} = q\vec{v} \times \vec{B} \qquad [1]$$

In this experiment, we will be able to determine the e/m ratio by measuring the electron's potential energy, amount of deflection, and the strength of the magnetic field. Once we have determined e/m, we will use Millikan's value for the electron charge to calculate the electron's mass.

The apparatus is self-contained and consists of a pair of Helmholtz coils, a low pressure gassed filled electron tube and power supplies. When an electric current is applied to the tubes filament electrons are released from the filament, the electrons are then accelerated through an electron gun by a voltage potential which can be varied to create an electron beam. This beam enters into the gassed filled tube ionizing the gas and becoming visible to the eye.

This potential difference imparts a change in the electrons potential energy, $\Delta U = e\Delta V$, where e is the charge of an electron. Due to conservation of energy, this causes a change in kinetic energy, $\Delta U = \Delta K$. Since the electrons are initially at rest where the potential is zero, the conservation of energy may be written as

$$eV = \frac{1}{2}mv^2 \qquad [2]$$

Where V is the potential supplied to the electron gun, e and m is the charge and mass of an electron and v is the velocity achieved by the electron as it passes through the electron gun.

Once the electron passes through the gun it continues on a path affected only by gravity. Within the tube this appears as a slightly downward bent line.

The electron beam trajectory can be altered by applying a magnetic field, B, within the region of the beams path. This is accomplished by a pair of Helmholtz coils. Helmholtz coils are two identical coils in dimensions and number of coils such that when arranged symmetrically such that their spacing between one another is equal to their radius. When current is supplied through both coils a uniform magnetic field is produced between the two coils primarily at the point ½ of their radius, at this point the electron gun of the vacuum tube will be located.

The field created by the pair of Helmholtz coils can be determined from the equation

$$\vec{B} = \frac{8\mu_o NI}{R\sqrt{5^3}} \quad [3]$$

Where I is the applied current, R is the radius of one of the coils, μ_o is the permeability constant of free space ($\mu_o = 4\pi \times 10^{-7}$ Tm/A), and N is the number of winding of the coil.
Too see how the equation is derived visit the web site
http://en.wikipedia.org/wiki/Helmholtz_coil

Each electron then experiences a magnetic force represented by equation [1], where q is the charge of the electron (-1.6022×10^{-19} C). In this experiment the electron beam is perpendicular to the magnetic field, so the magnitude of $\vec{F}_B$ becomes

$$F_B = evB \quad [4]$$

If the strength of the magnetic field is large enough (i.e. the current passing through the coils), the electron beam will be bent into a circular path, ever decreasing as the current though the coils is increased. The electrons moving though this circular path are experiencing a centripetal force equal to a product of its mass and its centripetal acceleration such that

$$F_c = m\frac{v^2}{r} \quad [5]$$

Where r is the radius of the electrons circular path.
For equation [6] combine equations [2], [4] and [5] to derive an equation for e/m

[6]

Task 1: Initial setup

- On the apparatus assure that the switches for current and deflection are in their mid positions, neither up or down this is their off state.
- Adjust the three control knobs fully counter clockwise.
- Turn on the apparatus using the red switch. A white glow should soon be present within the tube.
- Allow the tube to warm up for 5 minutes.
- A telescope is available to make precise measurements of the beams radius. It may be necessary for the person(s) making the measurements to make focus and height adjustments to the telescope as explained below.
- Position the telescope so that when looking through the telescope the gun cone can be seen, this may involved both horizontal and vertical adjustments. **Note the telescope inverts the image**.
- Once this has been accomplish and while viewing through the telescope adjust the focus by moving the eyepiece, inner barrel, in and out. **Note:** Two images of the gun may be seen, the near actual image and a farther reflected image. When properly aligned these two images should be seen as almost on top of one another. Slight adjustments to the telescope assembly may be necessary to achieve this, once you are satisfied adjust the focus for the near image. Also the telescope should be perpendicular to the gun not at some askew angle.

Task 2: Collecting Data.

Please note: To prolong the apparatus life, once the potential to the electron gun is established, it should not be in operation more than an hour to an hour and 15 minutes, please read through and understand what is to be accomplished before attempting the actual task.

The data to be collected is the voltage potential used to accelerate the electrons, the current passing through the wire to create the magnetic field and the relative positions of two opposite points of the circle in order to determine the diameter of the circle.

You will use two digital meters to read the current and voltage. Connections on the back of the apparatus are labeled.
The current is measured on the DC A scale 10 A range, and the hooked up between the COM and 10A sockets.

- Turn the accelerating voltage until the meter reads 160 Volts.
- An electron beam should now be visible within the tube. Turn the current switch upward a red led on the winding should indicate a clockwise direction.
- Adjust the current so that the meter reads 1 amp.
- The electron beam should now be in a circular path.
- Slide the telescope along the rail so that when looking through it the vertical cross line is tangent to the circle. It may be necessary to adjust the height so that the cross line is tangent to the circle.
- Record the position that can be read from the rail.
- Slide the telescope to the other edge of the circle and make a reading.

 Without adjusting the accelerating voltage and hopefully without disturbing the telescope assembly adjust the current up 0.10 amps, and repeat the circle measurements.
 Repeat for currents up to and including 1.50 amps.

 repeat the procedure to gather data for accelerating voltages at 180V and 200V.

Task 3: Evaluating the data

The magnetic field can be calculated using Equation [3] for each current.
Additional information for the apparatus:
R = 0.140m
N = 154 turns.

For each voltage setting and using your derived equation for e/m [6] a value for e/m can be obtained, then averaged.

Calculate a theoretical value for e/m from the accepted values of e and m_e and compare it to your results.

Determine your experimental value for the electron mass given that $e = 1.602x10^{-19}$.