PHY222 e over m Lab

The PASCO ModelSE-9638 e/m apparatus provides a simple method for measuring e/m, the charge to mass ratio of the electron. The method is similar to that used by J.J. Thomson in 1897. A beam of electrons is accelerated through a known potential, so the velocity of the electron is known. A pair of Helmholtz coils produces a uniform and measurable magnetic field at right angles to the electron beam. This magnetic field deflects the electron beam in a circular path. By measuring the accelerating potential difference (ΔV), the current to the Helmholtz coils (I), and the radius of the circular path of the electron beam (r), the e/m ratio can be easily calculated.

The e/m apparatus also has deflection plates that can be used to demonstrate the effects of an electric field on the electron beam. This can be used as a confirmation of the negative charge of the electron, and also to demonstrate how an oscilloscope works.

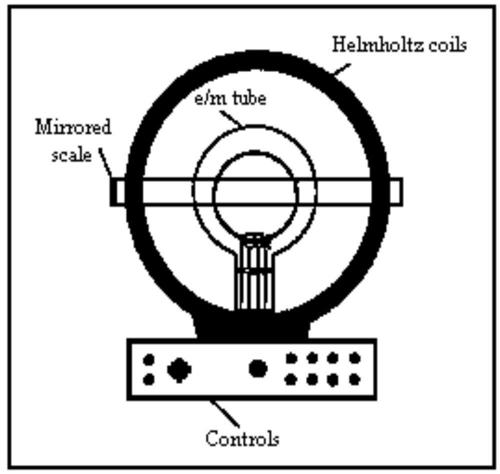

Figure 1 The e/m Apperatus

A unique feature of the e/m tube is that the socket rotates, allowing the electron beam to be oriented at any angle (from 0-90 degrees) with respect to the magnetic field from the Helmholtz coils. You can therefore rotate the tube and examine the vector nature of the magnetic field on moving charge particles. Other experiments are also possible with the e/m tube. For example, you can use a small permanent magnet instead of the Helmholtz coils to investigate the effect of a magnetic field on the electron beam. (You'll do these activities later)

Equipment

The e/m Tube – The e/m tube (Figure 2) is filled with helium at a pressure of 10^{-2} mm Hg, and contains an electron gun and deflection plates. The electron beam leaves a visible trail in the tube because some of the electrons collide with the helium atoms, which are excited and therefore radiate visible light.

The electron gun is shown in Figure 3. The heater heats the cathode, which emits electrons. The electrons are accelerated by a potential difference applied between the cathode and the anode. The grid is held positive with respect to the cathode and negative with respect to the anode, which helps to focus the electron beam.

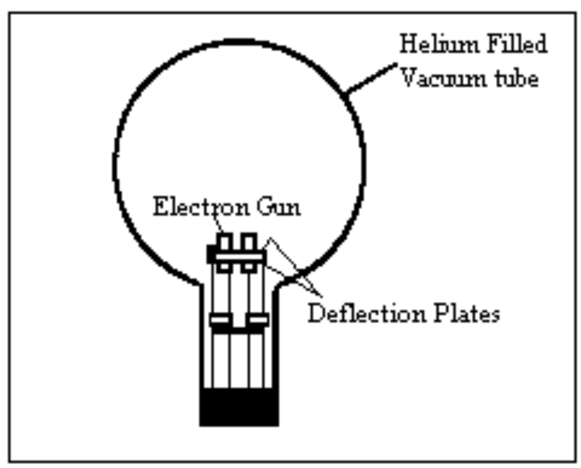

Figure 2 e/m Tube

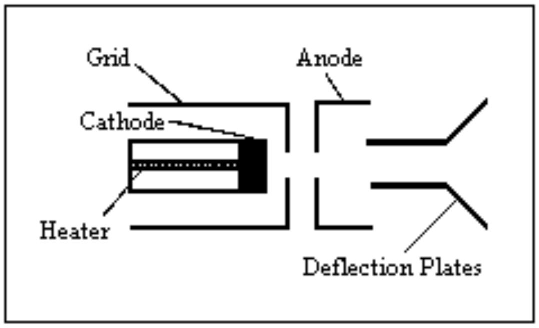

Figure 3 Electron Gun

The Helmholtz Coils – The geometry of Helmholtz coils – (the radius of the coils is equal to the separation between them) – provides a highly uniform magnetic field. Important information about the Helmholtz coils include:

Radius of the coils is 15.0 cm
Number of windings of each coil is 130

The Controls – The control panel of the e/m apparatus is straightforward. All connections are labeled. The hook-ups and operation are explained in the next section.

Cloth Hood – The hood can be placed over the top of the e/m apparatus so the experiment can be performed in a lighted room.

Mirrored Scale – A mirrored scale is attached to the back of the rear Helmholtz coil. It is illuminated by the lights that are lit automatically when the heater of the electron gun is powered. By lining the electron beam up with its image in the mirrored scale, you can measure the radius of the beam path without parallax error.

Additional Equipment Needed

Power Supplies:

6-9 VDC Low Voltage (ripple <1%) for Helmholtz coils.

150-300 VDC High Voltage accelerating potential and use the AC side of the high voltage unit to power the heater (set at 4-6 VAC).

Meters

Ammeter with 0-2 A range to measure current in Helmholtz coils.

Voltmeter with 0-300 V range to measure accelerating potential.

(The meters that are built in to the power supplies can be used in lieu of stand-alone meters)

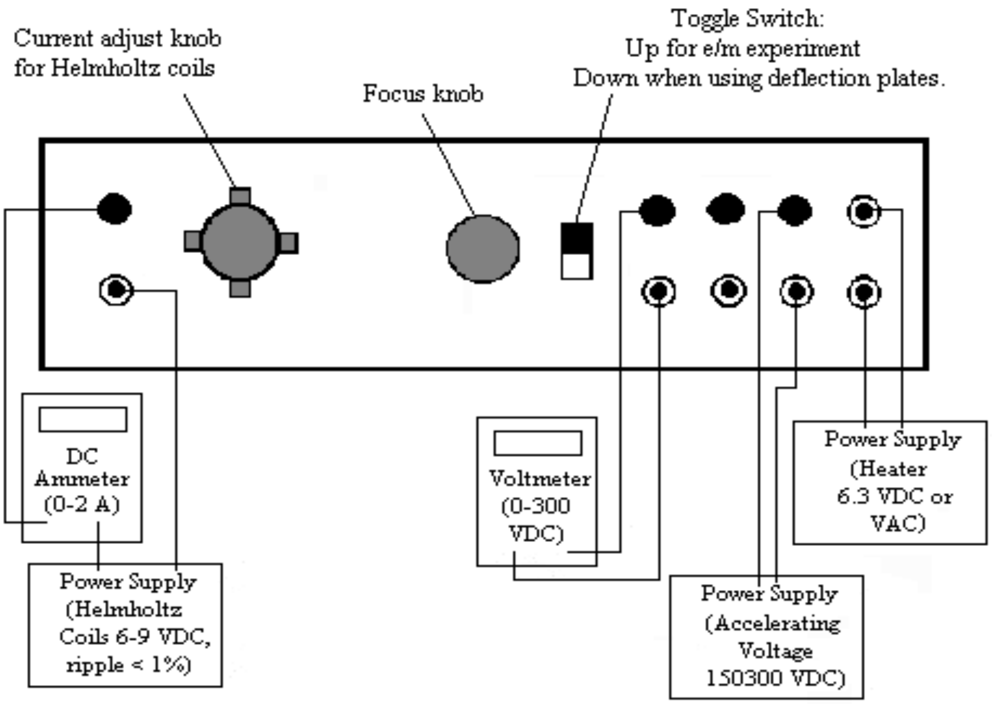

Figure 4
Helmholtz Coils
Control Panel

Operation – Measuring e/m

1. If you will be working in a lighted room, place the hood over the e/m apparatus.

2. Flip the toggle switch up to the e/m MEASURE position.

3. Turn the current adjust knob for the Helmholtz coils to the **OFF** position.

4. Connect your power supplies and meters to the front panel of the e/m apparatus, as shown in Figure 4.

5. Adjust the power supplies to the following levels:

Low Voltage Power Supply
Attach the low voltage power supply to the Helmholtz Coils on the left side of the control panel. Direction is important! Red to red: Black to black. The voltage should be set in the range of 6 – 9V DC.

High Voltage Power Supply
Use the DC side of the power supply set at 150-300V for the accelerating potential difference. Attach this to the Electron Gun Electrodes connectors on the control panel.

Use the AC side of the power supply set to 4 – 6V AC to attach to the Electron Gun Heater connectors on the control panel. Do NOT set higher than 6V AC or you could burn up the heater!!!

6. Slowly turn the current adjust knob for the Helmholtz coils clockwise. Watch the ammeter and take care that the current does **not exceed** 2.0 A.

7. Wait several minutes for the cathode to heat up. When it does, you will see the electron beam emerge from the electron gun and it will be curved by the field from the Helmholtz coils. Check that the electron beam is parallel to the Helmholtz coils (a flat, green circle with no pitch). If it is not, gently turn the tube until it is. Do not take the tube out of its socket. As you rotate the tube, the socket will turn.

8. Read the current to the Helmholtz coils from the Amps window on the low voltage power supply and the accelerating voltage from the Volts window on the high voltage power supply. Record your values below.

Helmholtz coil current: ___________A

Accelerating voltage: _____________V

9. Carefully measure the radius of the electron beam. Look through the tube at the electron beam. To avoid parallax errors, move your head to align the electron beam with the reflection of the beam that you can see on the mirrored scale. Measure the radius of the beam as you see it on both sides of the scale, and then average the results. Record your results below.

Radius of electron beam: __________cm

TURN ALL POWER SUPPLIES OFF AT THIS POINT!!

Analysis of e/m Measurement

The magnetic force (F_B) acting on a charged particle of charge q moving with velocity v in a magnetic field B is given by the equation: $F_B = qv \times B$
where F_B, v, and B are vectors and X denotes a vector cross product.

Recall this can be written in magnitude form as: $F_B = qvB\sin\theta$
where θ is the angle between the direction of v and the direction of B.

Since the electron beam in this experiment is perpendicular to the magnetic field created by the Helmholtz coils and the charge is an electron (e), the equation can be written simply as: $F_B = evB$

Recall that when a charge ***q*** moves with a velocity ***v*** into a perpendicular magnetic field ***B***, the path of the charge is deflected into a circle, and the F_B force becomes the "force that maintains circular motion". Use the process of ΣF_{IN} to derive the equation for calculating the e/m ratio. Show your work for this derivation in the space below. This process should be done with <u>*variables only*</u> (do NOT insert values at this point!) Note: the charge in this case is an electron, ***e***.

(This will be called Equation 1)

You already know the radius of the circular path, so in order to calculate e/m, you need to know the velocity of the electron (v) and the magnitude of the magnetic field (B).

The electrons are accelerated through the accelerating voltage (ΔV), and the potential energy they gain in this process is converted immediately into kinetic energy. In the space below, show how you would use this information to derive the equation for the velocity of the electrons. Again, <u>*variables only*</u> at this point!

(This will be called Equation 2)

The magnetic field produced near the axis of a pair of Helmholtz coils is given by the equation: **(This will be called Equation 3)**

$$B = \frac{N\mu_o i}{(5/4)^{3/2}\, a}$$

<u>Where:</u>

a = the radius of the Helmholtz coils (given earlier)

N = the number of turns on each of the Helmholtz coils (given earlier)

μ_o = the permeability const ($4\pi \times 10^{-7}$)

i = the current through the Helmholtz coils (as measured earlier)

Note: A derivation for this formula for magnetic field of a pair of Helmholtz coils can be found in most introductory texts on electricity and magnetism.

In the space below, substitute equations 2 and 3 into equation 1 to derive a final <u>*equation*</u> for e/m. Note: this final equation will look like e/m = (expression), and this expression to solve for e/m CANNOT contain either e or m! This final expression should contain measurements you took in lab, information about the apparatus, and the permeability constant. Use this equation and the known values to calculate your **O**bserved value for e/m, and record it in the space below.

e/m = ______________________C/kg

How does this **O**bserved value compare with the **A**ccepted value for e/m of the electron? Show your work to calculate the **A**ccepted e/m value, then use the Percent Error (E_R) calculation below to compare results (show your work):

e/m **A**ccepted value calculation:

E_R = [(O-A)/A]*100 calculation

What equation would you use if you wished to determine the period of the electron travel?

Changing θ

1. Turn the power supplies back on with the same settings as you had before, and allow sufficient time to let the cathode heat up to see the electron beam path.

2. *Carefully* rotate the e/m tube through some angle less than 45°. How does this change the path of the electrons? (Briefly explain)

3. How would you determine what the pitch is of the new electron beam path? (i.e., what equation would you use?)

4. Does the radius of the path change? (the answer is yes). What equation would you use to calculate the new radius of the electron beam path?

Rotate the e/m tube back to the position where the electron beam path is a flat circle. Now, bring one end of the bar magnet toward the center of the electron beam loop. What happens to the loop? Flip the bar magnet around and do the same thing with the other end and compare to your first results. Why does this happen? (Think in terms of "net" B-field that the electron beam is now experiencing).

Alternate B-Field Source

The current in the Helmholtz coils was the source of the B field. Dial the Helmholtz current down to zero, and what happens to the electron beam?

Now, with the Helmholtz current still at zero, bring one end of a permanent (bar) magnet into the vicinity of the e/m tube (near the beam). What happens to the electron beam now? What happens if you flip the bar magnet around and bring it toward the beam?

TURN OFF ALL POWER SUPPLIES AND RETURN ALL LAB SUPPLIES TO THEIR ORIGINAL CONDITIONS.

Lab Quiz next class period.
Lab notes can be used.

No equations will be provided, so be sure your lab notes are complete and all questions answered!

(Also suggest reviewing the CH28 "Circulating a Charged Particle" section)