Measuring e/m

(Vertical Scale Method)

Purpose

The purpose of this lab is to determine the charge to mass ratio of the electron.

Equipment

Pasco Model SE-9638 E/M Apparatus Power Supply, Elenco Power Supply, Pasco Model SF-9585A Digital Multi-Meter, DMM Lead, Banana/Banana (7) Computer - for analysis

Typical Setup



Introduction

The PASCO Model SE-9638 e/m Apparatus provides a simple method for measuring e/m, the charge to mass ration of the electron. The method is similar to that used by J. J. Thompson in 1897. A beam of electrons is accelerated through a known potential, so the velocity of the electrons 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 (V), the current to the Helmholtz coils (I), and the radius of the circular path of the electron beam (r), e/m is easily



calculated: $\frac{e}{m} = \frac{2V}{B^2 r^2}$. (The calculations are explained in a later section of this hand out.)

IMPORTANT: The circular electron beam should be large enough (adjust magnet current) so that it extends equally above and below the scale. This will be a judgment call on your part but it is a crucial part of the lab experiment. The path of the beam should cross the scale at a right angle to it.

Equipment Description

The e/m Tube—The e/m tube (see Figure 2) is filled with helium at a pressure of 10⁻²mm 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 helium atoms, which are excited and then 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 applied between the cathode and the anode. The grid is held positive with respect to the cathode and negative with respect to the anode. It helps focus the electron beam.

Caution: The voltage to the heater of the electron gun should NEVER exceed 6.3 volts. Higher voltages will burn out the filament and destroy the e/m tube.









The Helmholtz Coils—The geometry of Helmholtz coils—the radius of the coils is equal to their separation—provides a highly uniform magnetic field. The Helmholtz coils of the e/m apparatus have a radius and separation of 15 cm. Each coil has 130 turns. The magnetic field (B) produced by the coils is proportional to the current through the coils. 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. This scale is illuminated by lights, which automatically turn on when the heater to the electron gun is powered. <u>By lining up the circular electron beam with its image in the</u> <u>mirrored scale, you can eliminate the effect of parallax in the measurement of the radius</u> <u>of the beam path.</u>

Procedure

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.
- Connect your power supplies and meters to the front panel of the e/m apparatus, as shown in Figure 4 (below). (Full picture—last page. Figure 5)

Figure 4



5. Adjust the power supplies to the following levels. The voltmeter in Figure is not necessary because the meters on the Pasco SF-9585A power supply are of the same quality. (Note: Make sure all settings are in the zero position before turning on the power switch.):

Electron Gun

Heater:	6.3 VAC or VDC
Electrodes:	150 to 300 VDC
HelmHoltz Coils:	6-9 VDC

Caution: The voltage to the heater of the electron gun should NEVER exceed 6.3 volts. Higher voltages will burn out the filament and destroy the e/m tube.

- 6. Wait several minutes for the cathode to heat up. When it does, you will see the electron beam emerge from the electron gun.
- 7. Slowly turn the current adjust knob for the Helmholtz coils clockwise. Watch the ammeter and take care that the current does not exceed 2 A. The field from the Helmholtz coils will curve the electron beam. (Check that the electron beam is parallel to the plane of the Helmholtz coils. If it is not allow your instructor or lab tech to adjust it.)
- 8. Carefully read the current to the Helmholtz coils from your ammeter and the accelerating voltage from the voltmeter. Record the values in the data table
- 9. Carefully measure the radius of the electron beam. Look through the tube at the electron beam. To avoid parallax errors, move your head up-down, with one eye closed, to align the electron beam with the reflection of the beam that you see on the mirrored scale. Measure the extent of the outer edge of the beam (beam radius r_B) as you see it on the top side of the "zero" on the illuminated scale, and then average this value with the source radius (r_S). This average is your measured value of the circle radius. Record your results in the data table.

$$r_{c} = \frac{r_{B} + r_{S}}{2}; \quad r_{S} = 3.5 \ cm$$

Note 1: To 'line up' of each beam. Move your head up and down.

10. When using the mirrored scale in the vertical orientation there is more than one ONE correct value of the electron beam radius. It will be different for every set of magnet current and electron gun voltage measurements. Your task is to measure it accurately and precisely and to repeat the process for a total of five (5) sets of magnet current, beam voltage and beam radius r_B.

Data Analysis

Data Set	Accel Voltage (V)	Magnet Current (A)	r _B (cm)	r _C (cm)	$\frac{(\mathbf{Ir}_{\mathbf{C}})^2}{(\mathbf{A}\mathbf{-m})^2}$
1					
2					
3					
4					
5					

GRAPHICAL ANALYSIS

Plot a graph of V vs $/(Ir_C)^2$ using Excel. Fit the data with a linear trendline and determine the slope and the uncertainty in the slope (using LINEST). The value of the slope is the value of V/(Ir_C)² that you will use to determine your experimental value of the electron's e/m ratio.

$$\frac{e}{m} = \frac{v}{Br} = \frac{2\left(\frac{5}{4}\right)^3 a^2}{\left(N\mu_0\right)^2} \left(\frac{V}{\left(Ir\right)^2}\right) \xrightarrow{\text{Slope of the "V"}} \frac{\text{Slope of the "V"}}{\text{vs "(Ir_C)^2" graph}}$$

Report - This lab requires a full formal report. Follow the directions in the hand out **"Format for Formal Lab Reports."**

APPENDIX - Analysis of e/m Measurement

The magnetic force (F_m) acting on a charged particle of charge q moving with velocity v in a magnetic field (B) is given by the equation

$$F_m = qv \times B,$$

(where F, v, and B are vectors and \times is a vector cross product.) Since the electron beam in this experiment is perpendicular to the magnetic field, the equation can be written in scalar form as:

$$F_m = evB$$
 Equation 1

where e is the charge of the electron.

Since the electrons are moving in a circle, they must be experiencing a centripetal force of magnitude

$$F_m = \frac{mv^2}{r}$$
 Equation 2

where *m* is the mass of the electron, *v* is its velocity, and *r* is the radius of the circular motion. Since the only force acting on the electrons is that caused by the magnetic field, $F_m = F_c$, so equations 1 and 2 can be combined to give

$$evB = \frac{mv^2}{r}$$

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$$\frac{e}{m} = \frac{v}{Br}$$
 Equation 3

Therefore, in order to determine e/m, it is only necessary to know the velocity of the electrons, the magnetic field produced by the Helmholtz coils, and the radius of the electron beam.

The electrons are accelerated through the accelerating potential V, gaining kinetic energy equal to their charge time the accelerating potential. Therefore

$$eV = \frac{1}{2}mv^2.$$

Electron E/M Ratio 6A-E-over-M 06-11-13.doc The velocity of the electrons is therefore:

$$v = \left(\frac{2eV}{m}\right)^2$$

Equation 4

The magnetic field produced near the axis of a pair of Helmholtz coils is given by the equation:

$$B = \frac{[N\mu_0]I}{\left(\frac{5}{4}\right)^{\frac{3}{2}}a}$$
 Equation 5

A derivation for this formula can be found in most introductory texts on electricity and magnetism.

Equations 4 and 5 can be plugged into equation 3 to get a final formula for e/m:

$$\frac{e}{m} = \frac{v}{Br} = \frac{2V\left(\frac{5}{4}\right)^3 a^2}{\left(N\mu_0 Ir\right)^2}$$
 Do not use this form of the equation to calculate e/m.

where:

V = the accelerating potential

a = the radius of the Helmholtz coils = 15.0 cm

N = the number of turns on each Helmholtz coil = 130

 μ_0 = the permeability constant = $4\pi \times 10^{-7}$

I = the current through the Helmholtz coils

r = the radius of the electron beam path

$$(e/m)_{accepted} = 1.7589 \text{ x } 10^{11} \text{ C/kg}$$





Note: The digital ammeter is not shown is this diagram. It is shown, however, in Figure 4. The digital voltmeter shown in Figure 4 is not necessary due to the precision of the Pasco unit.