THE CHARGE-TO-MASS RATIO OF THE ELECTRON (e/m)

INTRODUCTION

In this experiment you will be measuring the charge to mass ratio, e/m, of the electron. The h/e apparatus consists of an electron gun, a helium filled vacuum tube, and a pair of Helmholtz coils (see Figure 1). The function of the electron gun is to emit a beam of electrons from a heated cathode and then accelerate the beam through a known potential. The helium tube is used to trace the electron beam as some of the electrons collide with the He atoms, which are excited, and then radiate visible light. The Helmholtz coils are used to produce a uniform magnetic field which will cause the electron beam to bend into a circular path. . The radius of the beam path can be determined by observing the electron beam in the mirrored scale. The actual beam seen by the observer must be superimposed on its image in the mirror to eliminate parallax

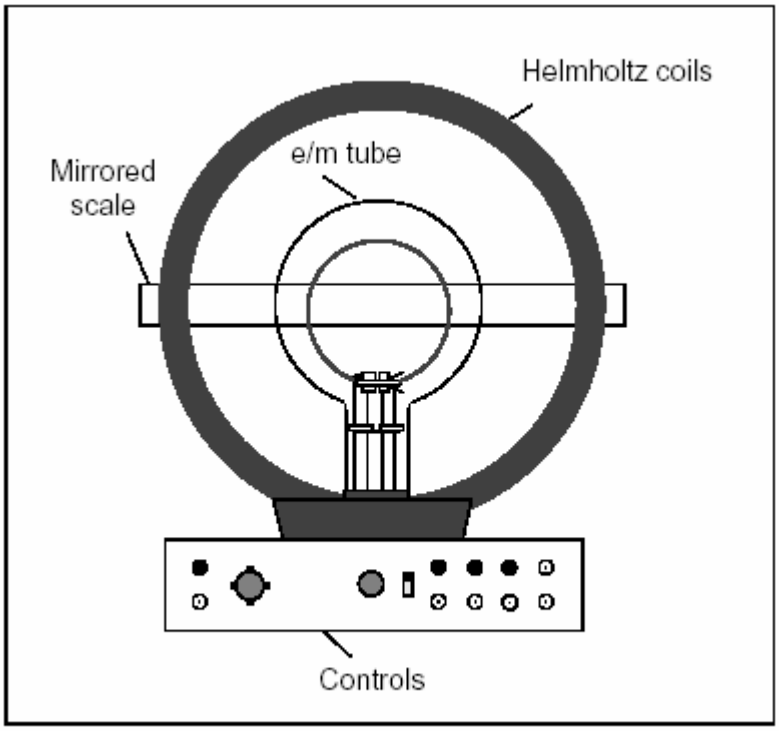


Figure 1 The e/m Apparatus

EQUIPMENT

1. e/m apparatus
2. 9 banana leads
3. low voltage power supply for heater (6-9 VDC)
4. low voltage power supply for Helmholtz Coils (6-9 VDC)
5. high voltage power supply (150-300 VDC)
6. digital ammeter (0-2A range)
7. digital voltmeter (0-300V range)

THEORY

A charged particle moving in a magnetic field (B) experiences a magnetic force given by the equation:

$$\mathbf{F}_m = q\mathbf{v} \times \mathbf{B} \qquad (1)$$

In this experiment the electron beam will be perpendicular to the B-field, thus equation (1) can be written as:

$$F_m = evB \qquad (2)$$

where 'e' is the charge on the electron.

Since the beam of electrons is perpendicular to the **B**-field, the electrons move in circular motion. Applying Newton's 2nd Law gives:

$$evB = mv^2/r \qquad (3)$$

Solving for e/m gives:

$$e/m = v/Br \qquad (4)$$

If an electron is accelerated through a potential 'V', then from conservation of energy we have that

$$\tfrac{1}{2}\, m\, v^2 = eV \qquad (5)$$

Solving for the speed of the electron gives:

$$v = (2eV/m)^{1/2} \qquad (6)$$

Using the Biot-Savart Law one can show that the B-field produced near the axis of a pair of Helmholz coils is

$$B = \frac{(N\mu_o)I}{a(5/4)^{3/2}} \qquad (7)$$

Substituting Eq. (6) and Eq. (7) into Eq. (4) gives our final result for the charge to mass ratio of the electron:

$$\frac{e}{m} = \frac{2Va^2(5/4)^3}{(N\mu_o Ir)^2} \qquad (8)$$

PROCEDURE

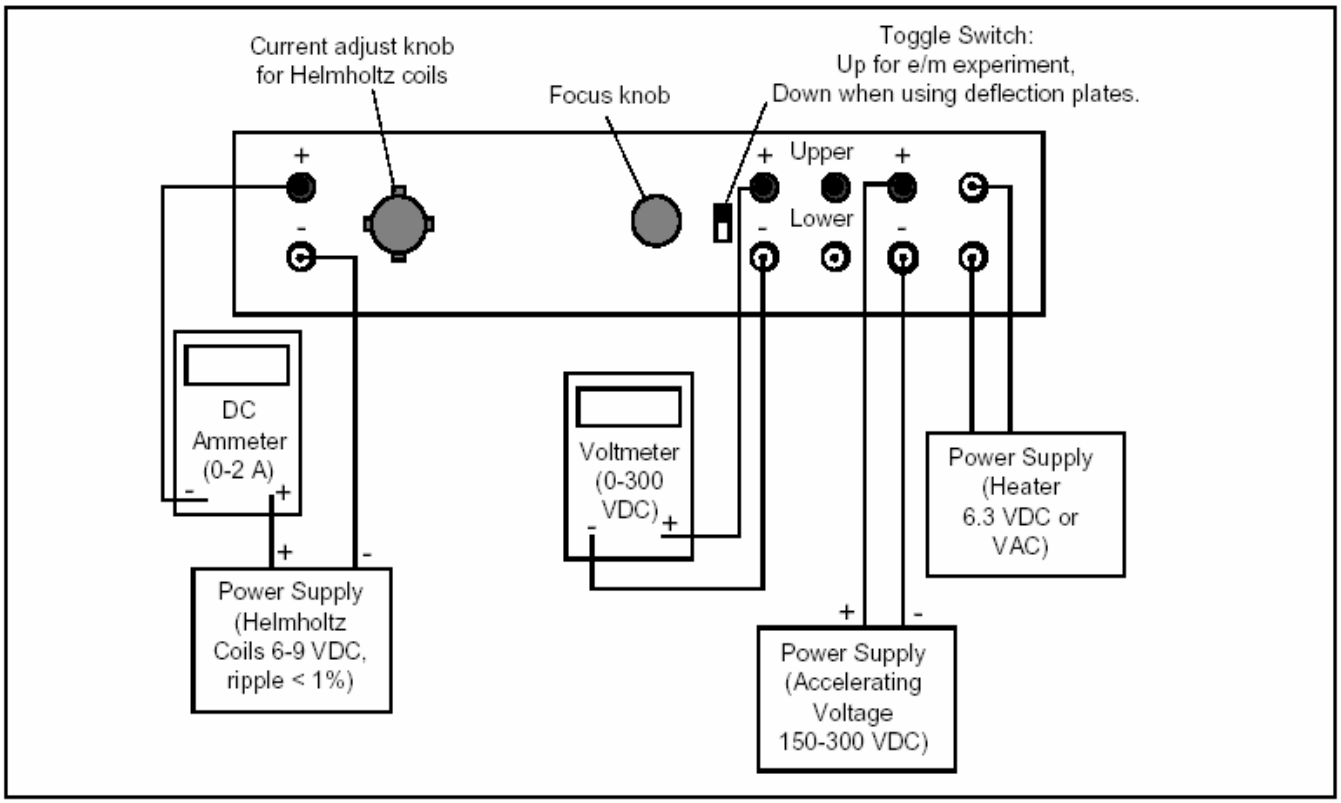
1. If you are working in a lighted room, place the hood over the e/m apparatus.

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 the your ammeter, voltmeter, and power supplies to the main control panel as illustrated below.

   Note: It's safest to turn the coil current control and the acceleration voltage fully counterclockwise before you turn on the power!!!



Connection for the e/m Experiment

5. Adjust the power supplies to the following levels:

   Heater: 6.3 VAC or VDC
   Accelerating Voltage: 150 V
   Helmholtz Coils: 6-9 VDC

> **LIMITS:**
> Electron gun filament voltage 6.3 volts
> Helmholz coil current ≤ 2 amperes
> Acceleration voltage $150 \leq V \leq 300$

6. Slowly turn the current adjust knob for the Helmholtz coils clockwise. Make sure the current does not exceed 2A on the ammeter.

7. Let the filament warm up for a couple of minutes.

8. Adjust the coil current so that the beam radius is successively (approximately) 4, 5, and 6 cm.

9. Record all radii, the Helmholtz coil currents, and the accelerating voltages.

   Note: You must be very careful to verify that the beam is superimposed on its mirror image before you record your radius measurements. It's best to measure 'r' on both sides of center and use the average value.

10. Repeat (8) now using 300 volts for the acceleration voltage.

11. Calculate the average radius of the Helmholz coils by measuring the inner and outer diameter of the coils. These Helmholtz coils contain 130 turns (N=130).

12. Include a data table in your report like the table below for both voltage settings.

DATA TABLE (150V/300V)

path radius (r)	coil current (I)	B of coils	e/m	% error

ANALYSIS

1. Calculate % error for each set of data.

2. Using the known electron mass and your average experimental e/m value, calculate the charge of the electron.

3. Comment on any systematic and random errors involved and how they may have affected your experimental results.

4. Prove that the B-field produced near the axis of a pair of Helmholtz coils is given by:

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

5. Show your step-by-step derivation for Equation (8).