February, 2001

e/*m* Ratio

Objective

- To study the effect of a magnetic field on a moving charged particle.
- To determine the electronic charge to mass ratio (*e*/*m*) using the *e*/*m* apparatus.

Theory

A charged particle of charge q moving with velocity $\boldsymbol{v}$ in a magnetic field $\boldsymbol{B}$ experiences a magnetic force

$$\boldsymbol{F_m} = q\boldsymbol{v} \times \boldsymbol{B}. \tag{1}$$

If the particle is an electron, Eq.(1) is written as

$$\boldsymbol{F_m} = -e\boldsymbol{v} \times \boldsymbol{B}, \tag{2}$$

and if $\boldsymbol{v}$ is perpendicular to the magnetic field, the magnitude of $\boldsymbol{F_m}$ is given as

$$F_m = evB, \tag{3}$$

where the direction of F_m, which is determined according to the left hand rule considering the minus sign for the electron, is at right angle to both $\boldsymbol{v}$ and $\boldsymbol{B}$.

Since $\boldsymbol{F_m}$ is perpendicular to the direction of the electron motion, it would move in a circular path, where $\boldsymbol{F_m}$ forms the centripetal force. According to Newton's 2nd law,

$$F_m = ma = \frac{mv^2}{r}, \tag{4}$$

where a is the centripetal acceleration, m is the mass of the electron, and r is the radius of the circular motion. Combining Eqs.(3) & (4) yields

$$evB = \frac{mv^2}{r}, \tag{5}$$

from which

$$\frac{e}{m} = \frac{v}{rB}. \tag{6}$$

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

The PASCO Model SE-9638 e/m apparatus provides a simple method (similar to that used by J.J. Thomson in 1897) for measuring *e/m* ratio (see Fig. 1). It consists mainly of a pair of Helmholtz coils, a glass tube, an electron gun, a mirrored scale, and control unit.

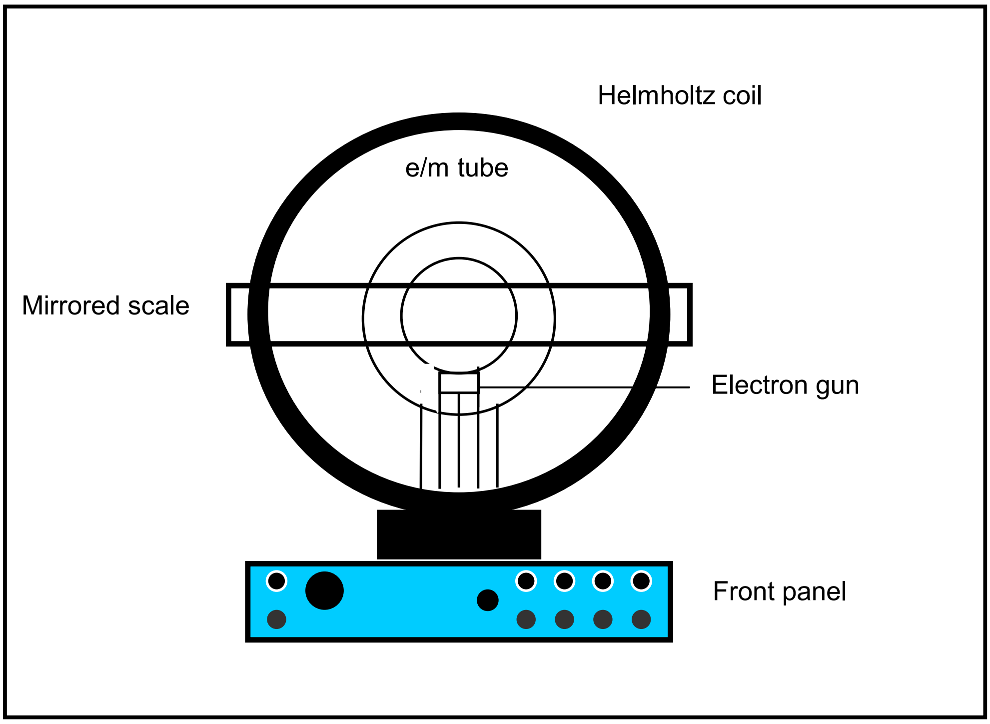

Figure 1: The e/m Apparatus

The glass tube is filled with Helium gas at a pressure of 10^{-2} mm Hg. The electron gun is shown in Fig. 2. The heater heats the cathode, which emits electrons (Caution: The voltage to the heater of the electron gun should never exceed 6.3 V, higher voltages will burn out the filament and destroy the e/m tube). The electrons are accelerated by an applied potential difference between the electrodes.

The grid is held positive with respect to the cathode and negative with respect to the anode, which helps to focus the electron beam. As the electron beam exits the anode's hole it 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 Helmholtz coils produce a uniform and measurable magnetic field at right angles to the electron beam. This magnetic field deflects the electron beam in a circular path the radius of which is measured at the mirrored scale.

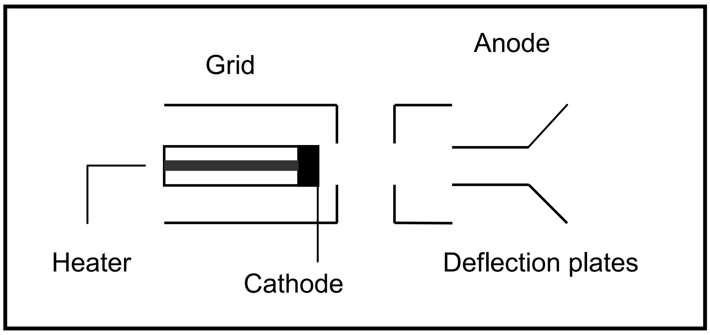

Figure 2: Electron gun

When the electrons are accelerated through a known potential (V), they gain kinetic energy where

$$eV = \frac{1}{2} mv^2. \tag{7}$$

The velocity of the electrons is therefore,

$$v = (2eV/m)^{1/2}. \tag{8}$$

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

$$B = \frac{\mu_o IN}{(5/4)^{3/2} a}, \tag{9}$$

where

μ_o is the permeability constant = $4\pi \times 10^{-7}$,

I is the current in the Helmholtz coils,

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

a is the radius of the Helmholtz coils = 15 cm.

Eqs.(8) and (9) can be plugged into Eq.(6) to get a final formula for e/m

$$\frac{e}{m} = \frac{2V(5/4)^3 a^2}{(\mu_o INr)^2}, \tag{10}$$

which can be rearranged as

$$V = \frac{e}{m} \frac{[\mu_o IN]^2}{2(5/4)^3 a^2} \cdot r^2. \tag{11}$$

A plot of V versus r^2 should results in a straight line where e/m can be determined from the slope.

Equipment

- UCHIDA e/m Experimental Apparatus.
- PASCO Low Voltage Power Supply.
- PASCO High Voltage Power Supply.
- Multimeters (2).
- wires (9).

Procedure

1. Connect the circuit as shown in Fig. 3 (make sure to use the 10 A socket of the Ammeter).

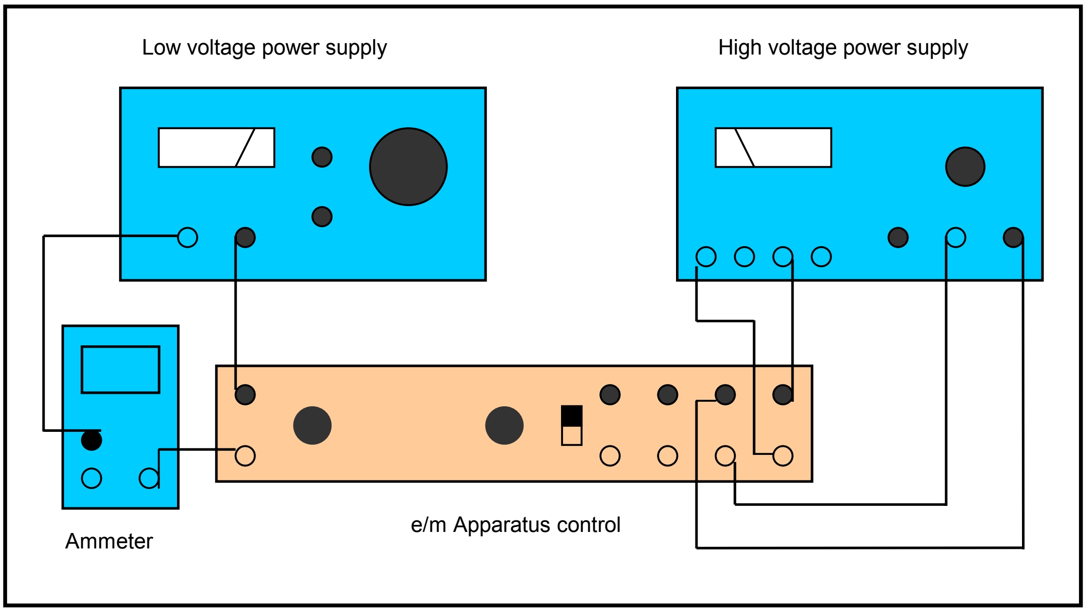

Figure 3: e/m connections

2. Flip the toggle switch up to the e/m MEASURE position.
3. Turn the current adjust knob of the low voltage power supply clockwise to maximum, and the voltage knob anti-clockwise to minimum.
4. Set the current adjust knob for the Helmholtz coils clockwise to maximum position.

5. Cover e/m Apparatus with the black hood.
6. Switch on the power of the two supplies.
7. Set the high voltage power supply electrode voltage to 250 V.
8. Turn the voltage adjust knob of the low power supply clockwise until the ammeter reads a current of 1.4 A.
9. Wait a minute for the cathode to heat up. When it does, you will see the electron beam emerging from the electron gun forming a circle. Check that the electron beam is parallel to the Helmholtz coils; if it is not, turn the tube until it is. Don't take the tube out of its socket; as you rotate the tube, the socket will turn.
10. Carefully measure the radius of the electron beam circle. 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 both from the left and right sides, calculate the average then, record your results in Table I.
11. For electrode voltages from 180 V-300 V fill the table, then plot V versus $(r_{avg})^2$ from which determine *e/m* ratio, then compare with the theoretical *e/m* ratio.

Table I

Electrodes (V)	r_L (cm)	r_R (cm)	r_{avg} (cm)	$(r_{avg})^2$ (cm^2)
180				
210				
240				
270				
300				

Questions

1. How does V, changes with r^2?
2. If instead of the electrons, protons were accelerated to the same velocity $\boldsymbol{v}$ at right angle to the same magnetic field $\boldsymbol{B}$, what differences would it make?
3. What is the effect of reversing the current direction in the Helmholtz coils?
4. How does the radius of the electron beam changes with the current I?