Charge to Mass Ratio (e/m) for the Electron

Objective: To measure the ratio of the charge of the electron (e) to its mass (m).

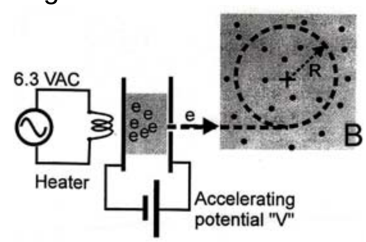
Introduction

The electrons used in the experiment are produced by a hot filament (heater). Next, they are accelerated through a potential difference, V, in an electron "gun". The potential energy lost is transformed into kinetic energy:

$$\tfrac{1}{2} m v^2 = e V \qquad (1)$$

After this, the electrons enter a uniform magnetic field, B, which is perpendicular to their velocity. In these circumstances, the magnetic force on the electrons has the magnitude

$$F_B = e v B \qquad (2)$$



Since the net (i.e.magnetic) force is perpendicular to their velocity, it forces the electrons to move on a circle (with radius ***r***), at constant speed ***v*** and an acceleration $\boldsymbol{a = v^2/r}$. Since $\boldsymbol{F_B}$ is the only significant force, from Newton's second law we get

$$F = m\, v^2/r \qquad (3)$$

Substituting equations (1) and (2) and rearranging, this relation yields:

$$\underline{e} / m = 2V / r^2 B^2 \qquad (4)$$

The expression (3) can be rewritten as $\boldsymbol{V = (B^2/2)(e/m) * r^2}$ (5)

If one draws a ***graph V vs r²*** it should be a *straight line passing by origin with slope* *Slope* $=(B^2/2)(e/m)$ (6)

Then, one can calculate $e/m = Slope * (2/B^2)$ (7)

The magnetic field in apparatus used in this experiment is produced by a set of Helmholtz coils. Using the geometry of the coils and the number of turns, one may find that the strength of magnetic field in central area is given by expression $B=(4/3)^{3/2}\mu_o NI/R$. In case of our Helmotz sets(given number of turns N and radius R) this expression is simplified to :

$$B(T) = 7.80 \times 10^{-4}\, I \qquad (8)$$

By substituting (8) into relation (7), one gets:

$$e/m\ [C/kg] = Slope * 2 / (7.8 \times 10^{-4} * I)^2 \qquad (9)$$

where: r = the radius of the electron orbit in metres
I = the current in the coils in amperes

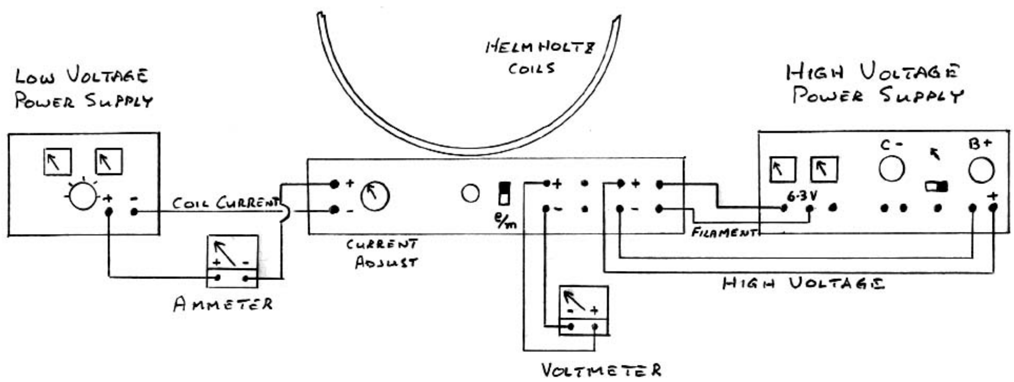
General Adjustments

1) In this experiment, one must take into account the effect of the magnetic field of earth. The vertical component is not a problem because the effect cancels out over the orbit of the electrons. To cancel the effect of the horizontal component, ***the plane of the Helmholtz coils must be aligned parallel to it.*** Use a magnetic compass to align the coils with the horizontal component of the earth's field. This must be done with the current in the coils

turned off. Also, move the apparatus to the edge of the workbench and move all meters and other instrument at least a foot away from the coils.

2) Connect the apparatus to the low voltage power supply, the high voltage power supply (HVPS), a voltmeter and ammeter as shown in the diagram below. Make sure both power supplies are turned off and the control knobs are turned to zero. Use the highest scale on both meters until you know the size of the voltage and current you will be measuring.
3) Put the DC ON switch of the HVPS to "STANDBY" and turn the B+ knob to zero. Switch the AC power on and wait a minute or two for the filament to start glowing.

4) Turn the current adjust switch for the Helmholtz coils to zero and set the selection switch to e/m. Turn the control knob on the low voltage power supply to zero, and then turn the supply on.



MAKE SURE THE FILAMENT OF THE ELECTRON GUN IS CONNECTED TO THE **6.3 VAC** TERMINALS OF THE HIGH VOLTAGE POWER SUPPLY. **HAVE YOUR TEACHER CHECK ALL CONNECTIONS BEFORE TURNING ON EITHER POWER SUPPLY.**

5) Switch the HVPS from "Standby" to "DC ON" and gradually increase the B+ control until the voltmeter reads 150 V. A green beam should appear in the glass envelope as the electron beam collides with the mercury vapour inside. Adjust the focus control to obtain as sharply defined a beam as possible.

NOTE: At this point, we will have to turn off the lights in the lab to make the beam more visible. You can also use the cloth hood supplied to shield out excess light. If the High Voltage Power Supply starts blinking, switch it to Standby and call over the teacher.

6) Turn the current adjust on the apparatus about half way up. Switch the low voltage power supply(EPSCO) to 0 - 16 V , turn it on and raise the current through ammeter until the electron beam is curved into a circle filling about 2/3 of the glass envelope. Check to see that the electron beam makes a closed circle bringing it right back between the two struts which take current to the filament. If it does not, **carefully and gently** rotate the glass envelope until the beam does form a closed circle. Note the shape of the path of the beam when it does not close.

Part A: measuring e/m value

1) Set the current in the coils to a ***fixed value (I=1 to 2A)which means keeping B magnitude constant. For this*** adjust both the voltage control on the low voltage power supply and the current adjust knob on the e/m apparatus. The beam should form a fairly small circle. Watch the ammeter

carefully when you do this to make sure it does not go off scale. ***Record the value of the current and keep it constant during measurements. Record the corresponding high voltage value.***
In this experiment, you will increase gradually the accelerating ***voltage*** (read on the voltmeter) ***and for each value you have to measure the radius of circular electron orbit***.

Measuring the radius:
The radius of the circular beam is measured using the illuminated scale behind the glass envelope. Since it is difficult to ensure that the zero on the scale is at the center of the circle, read the position of the left side of the circle, r_L, and the position of the right side of the circle, r_R, and calculate the average radius:

$$r = (r_L + r_R) / 2 \qquad (10)$$

The scale has an anti-parallax mirror behind it. When making the measurements, position your head so that the image of the beam in the mirror is aligned with the beam itself and the scale goes across the middle of the circle as shown below:

When you are properly aligned, the markings in the part of the scale you are using appear sharp and somewhat darker than the rest of the scale. If you are not properly aligned, they will be bright and fuzzy or doubled.

2) Keeping I constant, increase the voltage in five to six steps from 150 V to 300 V. **Do not exceed 300 V!** At each value of V, measure the radius of the electron path, record the value of V and make sure that I is still at its fixed initial value. Record all values in a table.

Based on recorded data, draw the graph1 $V = V(r^2)$. Fit this graph by a straight line passing by origin and get out its slope. Use the expression (9) to estimate e/m value for electron. Use the uncertainties of measurements for V and r, to find uncertainty of e/m value. Compare the result to the officially accepted value for e/m.

Part B: Verifying the expression for the radius of circular orbit (keep voltage constant)
At first, use the expression (1 to 3) to get the relation $r = (m/e)*v*(1/B)$ (11)
This is a straight line passing by origin; its slope is Slope $=(m/e)*v$ (12)

1) Reduce the accelerating voltage and keep it to a *fixed value* (150 to 200 V). Then vary the current over a wide range (1 to 3*A*) to obtain five to six readings. At each **value of I**, make sure that the voltage is at *chosen fixed value* and **measure the radius** of the circular beam. Record I, r values and related uncertainties in a table. With these data draw the graph 2 **r = r(1/B),** fit it by a straight line and use its slope to calculate the speed of electrons from (12) $v = Slope*(e/m)$.
Then compare this value to that derived from expression (1) $v = [(e/m)*2V]^{1/2}$

Analysis:

Calculate the ***best estimation, absolute uncertainty and precision*** for e/m from graph1 in Parts A.
Calculate the ratio e/m by using the values of e and m for the electron in your text book. Use precision and accuracy to compare your result to this value.
Use the precision to compare the estimation for electron speed (part B) to the theoretical value (1).

Conclusion: Does your measured value of e/m agree with the text book value? What is the main source of random uncertainty? Is there evidence for a systematic error in your measurements?