Experiment No. 3

Determination of Specific Charge (e/m) of an Electron

I. OBJECTIVES

- To determine the order of magnitude of charge-to-mass ratio of an electron

II. BACKGROUND [18]

The experiment of J. J. Thomson in 1897 on the measurement of the charge-to-mass ratio (e/m) of an electron provided the best experimental evidence available at that time of the existence of electrons. He showed that electrons, which he called corpuscles, follow well-defined paths, have a well-defined charge-to-mass ratio, and have mass, momentum, and energy that can be localized in space; that is, electrons show the attributes of a particle. He demonstrated that an electron beam can be deflected by an electric field and magnetic field.

Thomson's experiment consists basically of what we will find in a television picture tube: an evacuated tube where electrons are emitted from a hot filament and accelerated by an applied potential difference.

Passing through the slit in a screen, the electrons then enter a region in which they move perpendicular to an electric field and magnetic field; these two fields are perpendicular to each other, in an arrangement called crossed fields, whose effect is to deflect the electrons in opposite directions. The beam striking the fluorescent screen at the other end produces a bright spot. By measuring the displacement of the electron on the screen when only electric field is applied (magnetic field is turned off) and by calculating the electron speed when the magnetic force and electric force on the electron cancel each other out, Thomson was able to arrive at a formula for determining the charge-to-mass ratio. Thomson then put forward a very daring and important claim - which turned out to be correct - that electrons are a constituent of matter. He further concluded that electrons were lighter than the lightest known atom (hydrogen) by a factor of more than 1000 (the exact ratio proved later to be 1836.15).

The mass of the electron is difficult to determine experimentally. It is easier to determine the specific charge of the electron e/m from which the mass of the electron can be calculated if the elementary charge is known.

If a particle carrying an electric charge q moves with a velocity v in a magnetic field B that is at a right angle to the direction of motion, it will experience the **Lorentz force** given by $F = qv \times B$. This force, because of the vector product, is always perpendicular to both the magnetic field and the direction of motion. A constant force that is always perpendicular to the direction of motion will cause a particle to move in a *circle*. This fact will be used in this experiment to determine the charge to mass ratio of the electron by measuring the radius of that circle.

In this experiment, an electron will be allowed to travel in a region where there is a uniform magnetic field that runs perpendicular to its direction of motion. The electron's path will be deflected and thus it would travel in a circular path with constant speed. This deflecting force which is the net centripetal force on the electron, given by

$$\boldsymbol{F = m\frac{v^2}{r}} \quad (1)$$

is due to the magnetic field providing a magnetic force with magnitude $F = evB$. Combining these two equations, the electron then moves uniformly in a circle with radius

$$\boldsymbol{r = \frac{mv}{eB}} \quad (2)$$

This equation contains two assertions which are capable of experimental verification: *the radius of the path increases in proportion to the velocity v of the electrons and in inverse proportion to the magnetic flux density B.*

If the electron is accelerated by thermionic emission from a filament by an accelerating voltage V_a , its speed is determined from the relation:

$$\boldsymbol{eV_a = \frac{1}{2}mv^2} \quad (3)$$

Therefore the radius of curvature of the electron's path must increase in proportion to the square root of V_a. When the magnetic field is provided by a pair of Helmholtz coils, the magnetic field strength is determined by measuring the current through the coils given by:

$$\boldsymbol{B = \mu_0 \left(\frac{4}{5}\right)^{3/2} \frac{nI_c}{d_c/2}} \quad (4)$$

where n is the number of turns, d_c the diameter of the coils and μ_0 is the permeability for vacuum. The radius of the path must then be inversely proportional to the coil current I_c . And the charge-to mass ratio (e/m) may then be calculated using equations (2), (3), and (4):

$$\frac{e}{m} = \frac{V_a {d_c}^2}{2\left(\frac{4}{5}\right)^{3/2} {\mu_0}^2 n^2 {I_c}^2} \left(\frac{1}{r^2}\right) \qquad (5)$$

The apparatus to be used in this experiment is shown in Figure 31. The main components of the set-up are the fine beam tube and the Helmholtz coils.

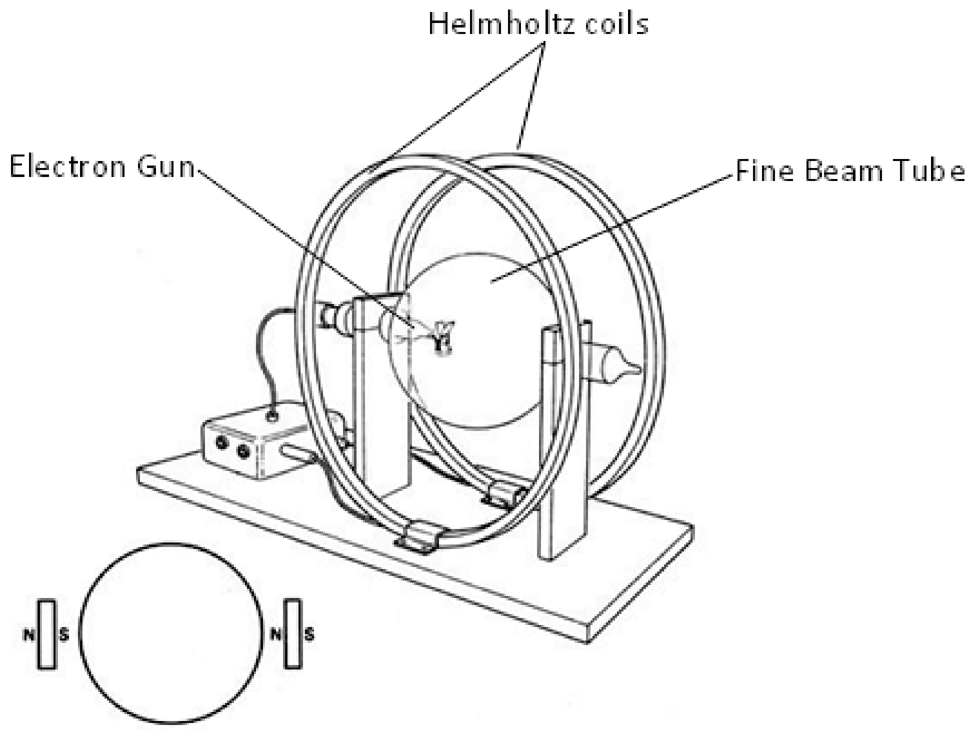

Figure 31. Apparatus used to determine the e/m ratio

The fine beam tube is a spherical glass tube containing some noble gas under low pressure. An electron beam inside the glass tube produces a beam of electrons. As the electrons collide with the gas molecules, the gas molecules are stimulated to emit light which makes it possible for us to see the path that the electrons traverse within the glass tube. The Helmholtz coils supply the magnetic field that forces the electrons to move in a circular path.

Note that the tube is extremely fragile, and the wires sticking out from the tube have current and voltage, so **be very careful**.

III. PROCEDURES [18]

(The set-up has been pre-arranged by the lab technician)

1. Switch on the e/m apparatus. Start the magnetic field in the coil by turning on the power supply for the coil. **Note that there is a ten minute warm-up time before you should take final measurements**. Get the current reading as registered in the meter in the power supply.
2. Bring the anode potential in the tube to *100 V*. Observe the circle formed by the electron beam. Using the mirror placed at the back of the tube, measure the diameter of the circle formed by the electron beam. (*Note*: A masking tape with several marks is pasted on the mirror. To measure the diameter of the circle, position the mirror in such a way that the luminous beam, its image and the corresponding marks coincide without parallax)
3. Repeat #2 but with the anode potential increased by *25 V*. Repeat this until you reach an anode voltage of *250 V*.
4. Tabulate your results using the table below. Make a graph of V_a vs. r^2. Estimate the best-fit line for your data points and solve for charge-to-mass ratio, e/m, using the slope for your line and equation (5).

DATA

Table:

Anode Voltage (V)	**Radius, r** (cm)	**Radius^2, r^2** (cm^2)
100		
125		
150		
175		
200		
225		
250		

μ_0 = 1.26×10^{-6} Vs/Am
I_c = ______________
d_c = ______________
n = ______________

slope = _____________

$(e/m)_{THEO}$ = 1.758×10^{11} C/kg
$(e/m)_{EXP}$ = _____________

IV. EVALUATION

1. The Earth's magnetic field is approximately 0.1 mT and is pointing into the ground at an angle of about 66 degrees with respect to the horizontal. Discuss how much difficulty the Earth's magnetic field will cause in your experiment.
2. If it were possible to arbitrarily orient the apparatus, in what direction (parallel, anti-parallel, perpendicular, other) should it be aligned in order to minimize the effects of the Earth's magnetic field? Explain your reasoning
3. If the tube were turned so that the velocity of the electrons is no longer perpendicular to the external magnetic field provided by the Helmholtz coils, how would the results of your experiment vary? How would the path of the electrons vary?