Experiment 9

Measurement of the Mass of an Electron

1. Introduction

An electron traveling with a speed, v, perpendicular to a uniform magnetic field, B, will experience a force, F, with a magnitude,

$$F = evB \tag{1}$$

where e is the charge of the electron. The direction of the force is perpendicular to the plane defined by the direction of v and B. The force is always perpendicular to the direction of motion of the electron. The electron moves in a circular path of radius r, with the magnetic force supplying the centripetal force. That is

$$F = evB = F_c = \frac{mv^2}{r} \tag{2}$$

where m is the mass of the electron. Solving for v, we have

$$v = \frac{eBr}{m} \tag{3}$$

The electron speed v is acquired by accelerating the electron through a potential difference,

$$eV = \frac{1}{2}mv^2 \tag{4}$$

substituting for v we find

$$eV = \frac{1}{2}m\left(\frac{e^2B^2r^2}{m^2}\right) \tag{5}$$

which reduces to

$$\frac{e}{m} = \frac{2V}{B^2r^2} \tag{6}$$

Hence, by knowing or measuring e, V, B, and r, the mass of the electron can be computed.

2. Procedure

The apparatus used in this experiment consists of a cathode tube, Helmholtz coils, two power supplies and an ammeter. The cathode ray tube is filled with hydrogen gas at low pressure of about 0.01 mm Hg. In some tubes, hydrogen gas is replaced by mercury vapor. Electrons collide with hydrogen, ionize them, and when atoms recombine with stray electrons, the characteristic green light is emitted. The emission occurs only at the points where ionization took place; therefore, a beam of electrons is visible as a luminous streak in a dark room.

The tube used in the experiment has been designed in such a way that the radius of the circular path of the electron beam can be conveniently measured. The electrons are emitted by the indirectly heated cathode, and are accelerated by the applied potential V between the filament and the anode. The cathode and the anode are constructed in such a way that only a narrow beam is allowed to pass the anode. Outside the anode, the electron beam moves with constant speed. When the beam is inside a magnetic field, it will move along the circle with a diameter given by Eq. 2.

A pair of Helmholtz coils produce an almost uniform magnetic field near the center of the coils which can be given by

$$B = 8\mu_o NI/\sqrt{125}\, a \qquad (8)$$

B is the magnetic field in teslas, N is the number of turns of wire in each coil, I is the current through the coils in amperes, and a is the mean radius of each coil in meters, which is equal to the distance between the coils. In the Helmholtz coils used in the experiment the number of turns is 130 and the radius is 15 cm.

Connect the heater and the anode of the vacuum tube to the high voltage power supply. The heater should be connected to a 6 V terminal. The anode voltage should be between 150 and 300 V. The coils have their own power supply with the voltage set to 12 V. Check the wiring (Fig. 1) and if you have any questions, ask the assistant for help. Turn on the power. As soon as the cathode starts to glow, increase the anode voltage so that the beam will be as sharp as possible. Do not increase the potential above 300 V.

Turn on the power supply of the Helmholtz coils. Select a value of the current in the coils; it should be between 0.5 and 2 A. Compute the magnetic field. Measure the diameter of the circular beam and record the current in the coils and the accelerating potential between the anode and the cathode. Increase the accelerating potential and record the beam radius. Repeat this procedure for 4 different accelerating potentials. To reduce the experimental error, read the beam diameter several times.

Repeat the above procedure with a different value of the coil current. You should have at least 10 different readings for different combinations of experimental parameters. From Eq. 6 find the e/m ratio and then calculate the mass of the electron, assuming that its charge is known and equals $e = 1.602 \times 10^{-19}$ C.

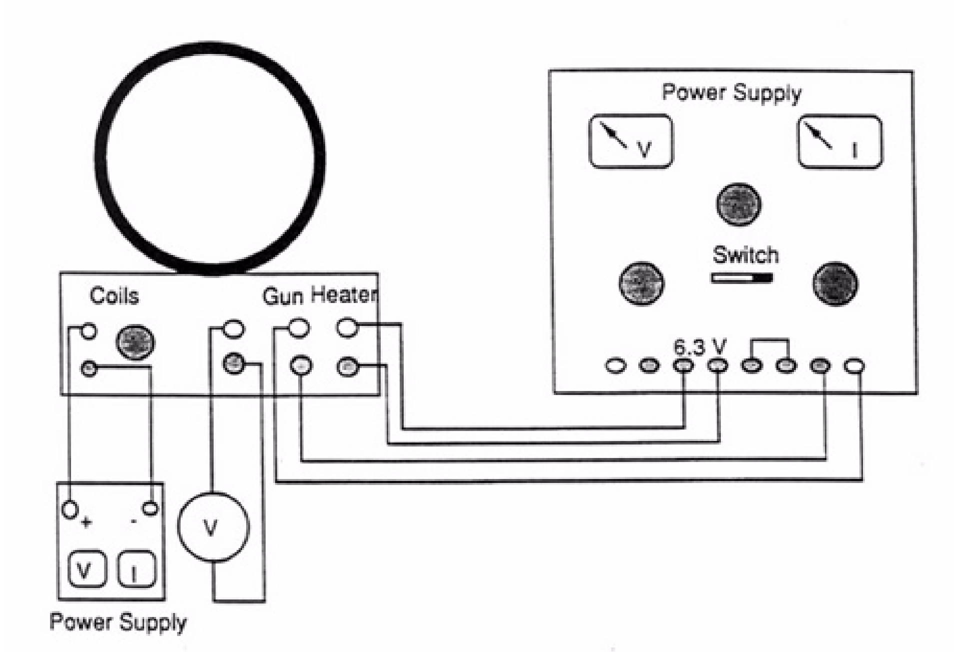


Fig. 1 Experimental set-up.

Since you have at least 10 experimental data points for m you can determine the mean value, <m>, and the standard deviation, Δm. The mean value and standard deviation are defined as

$$<\mathbf{m}> = \frac{\sum \mathbf{m_n}}{\mathbf{N}} \quad \text{and} \quad \Delta\mathbf{m} = \sqrt{\frac{\sum(\mathbf{m_n} - <\mathbf{m}>)^2}{(\mathbf{N}-1)}}$$

m_n are the measured values, n is the running number which varies from 1 to N, and N is the total number of points. Within the error, the mean value should be equal the expected textbook value, if not, discuss discrepancy.

3. Report

Present the results in the form of a table

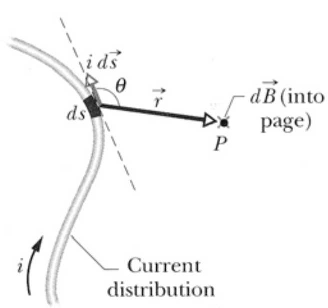
Coil current	B	Anode voltage	Radius of circle	e/m	m
[A]	**[Ts]**	**[V]**	**[m]**	**[C/kg]**	**[kg]**

Calculate the mean value of mass and estimate the error.

In the introduction, discuss one of the following topics:

1. e/m ratio can also be found from the method used by Thompson. Explain the principle difference between beach method.
2. Discuss the effect of the earth's magnetic field on the result of this experiment. Could you correct this effect? How?
3. Compute the velocities of electrons for all accelerating voltages used.

(For 20481 and 20484) Use the Biot-Savart law to derive equation 8 for the magnetic field. Find the change in B as you move a distance r from the center between the coils.



$$d\vec{B} = \frac{\mu_o}{4\pi} I \frac{d\vec{s} \times \vec{r}}{r^3}$$ law of Biot and Savart