Mass of the Electron Informal Experiment

Purpose

What is the inertial mass of the electron?

Materials

high-voltage direct-current power source, air-core solenoid, 6AF6G vacuum tube, low-voltage power source, ammeter, voltmeter, corks.

Introduction

When J.J. Thomson experimented with cathode rays in the 1890s, he measured the ratio of the electron's charge to its mass. He was unable to measure either value individually, because he needed to know the other one first. The charge of the electron was measured in the early 1900s by Robert Millikan, and then the electron's mass could be calculated. In this experiment, you will apply the same physical principles that Thomson used, but you will be able to determine the electron's mass directly because you can use the value of its charge. Your experiment will not be as precise as Thomson's because your apparatus is smaller than his, and you will have less time and opportunity to adjust it. But your data will enable you to calculate the electron's mass within the correct order of magnitude.

Pre-Lab Questions

In this investigation, you will observe and measure the path of electrons moving through a magnetic field inside a solenoid. In the Measurement of a Magnetic Field experiment, you used the equation $B = \mu_0 n I$ to determine the strength of the magnetic field inside the solenoid. The electrons in this experiment will be moving in a vacuum tube, but you can assume that the force on them is the same as if they were moving along a wire.

If you know the value of the current through the solenoid, you can use your results from the Measurement of a Magnetic Field experiment to find the strength of the magnetic field inside the solenoid.

1. Describe how you can use your results from the Measurement of a Magnetic Field experiment to find the strength of the magnetic field inside of solenoid.

In Section 20-12 of your textbook, you learned how the *q / m* ratio of a charged particle moving in electric and magnetic fields can be determined.

2. Show that the *q / m* ratio of a charged particle moving in a magnetic field alone is given by equation 1:

$$\frac{q}{m} = \frac{v}{BR}$$

   where *v* is the velocity of the charged particle, *B* is the magnitude of the magnetic field, and *R* is the radius of the circular path of the particle in the field. Show your calculation on a separate sheet of paper.

3. Solve the equation 1 for *m*. Show your calculation on a separate sheet of paper.

The speed of the electrons in a vacuum tube depends on the potential *V* applied between the anode and the cathode of the tube. The electrons accelerated by this potential acquire a kinetic energy that is equal to the electric potential energy they have at the cathode. This relationship can be written as equation 2:

$$Vq = \frac{1}{2}mv^2$$

You can substitute for m in this equation, using the expression you wrote in answer to question 3. If you then solve the resulting equation for v, you will find that the speed of the electrons striking the anode can be determined from measurements of only three values: B, V, and R.

4. Substitute for m in equation 2, and solve for v in terms of B, V, and R. Show your calculation on a separate piece of paper.

You now have three equations: one for B, one for m, and one for v. In order to find the velocity of the electrons moving in a magnetic field you must first find the strength of the magnetic field, B. You can do this by measuring the current I, through the solenoid. You can next measure the accelerating potential V and the radius of curvature R of the path of the electrons. Then you can calculate v. Knowing v, you can calculate m.

Thus, in this experiment, you need to measure I, V, and R to calculate B, V, and m.

Procedure

A. Set up the tube circuit.

The 6AF6G vacuum tube for this experiment is a commercial "tuning eye" tube used in radios. Figure 1 shows its internal construction. The cathode (K) at the center is heated red hot by the spiral heating element around it. Electrons from all points on the cathode are accelerated outward toward the bowl-shaped anode (A), except where they are blocked by the deflectors (D and D'). The anode is coated with a fluorescent material that glows when electrons strike it. Each spot that glows indicates the end of one electron's path from the center of the tube. You can infer the shape of the paths from the shape of the glowing areas on the anode.

Connect the vacuum tube, the power supplies, and the voltmeter as shown in Figure 2. Double check your wiring to make sure you do not damage the equipment when you turn it on. Set the control on the high-voltage source to its lowest position and turn on both power supplies. The cathode should get hot enough to emit electrons within about one minute. You can then turn up the high-voltage control until you see a fan-shaped glow on the anode. The reading from your voltmeter will give you the accelerating potential V.

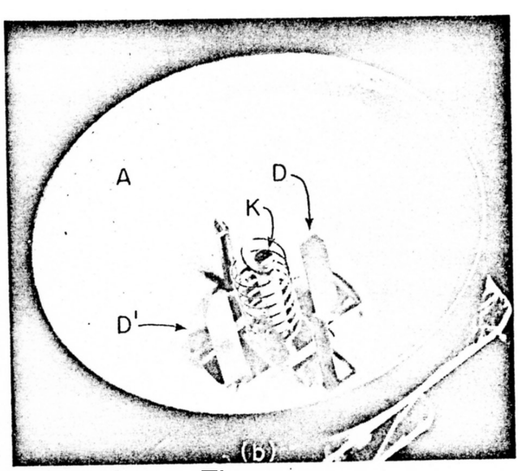

Figure 1

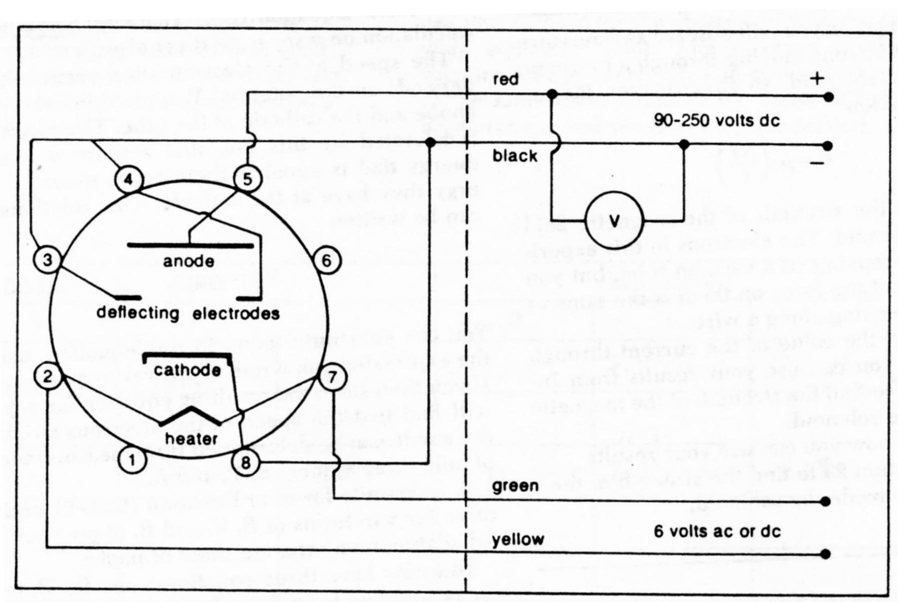

Figure 2

B. Set up the solenoid circuit.

When you are sure the circuit is working properly, connect the solenoid, the ammeter, and the low-voltage power source as shown in Figure 3. Set the power source to its lowest position. Then place the solenoid in a vertical position over the vacuum tube, as shown in Figure 4. As the current is increased, the magnetic field inside the solenoid should be sufficient to bend the pattern on the anode. Vary the setting of the power source and observe how the pattern changes. The current measured by your ammeter allows you to calculate *B*.

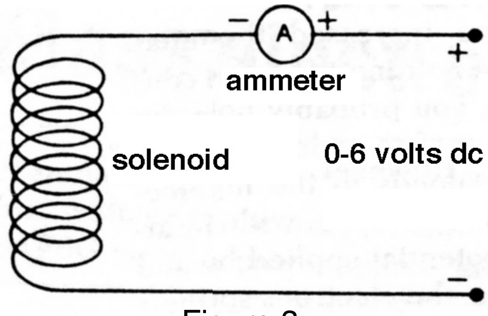

Figure 3

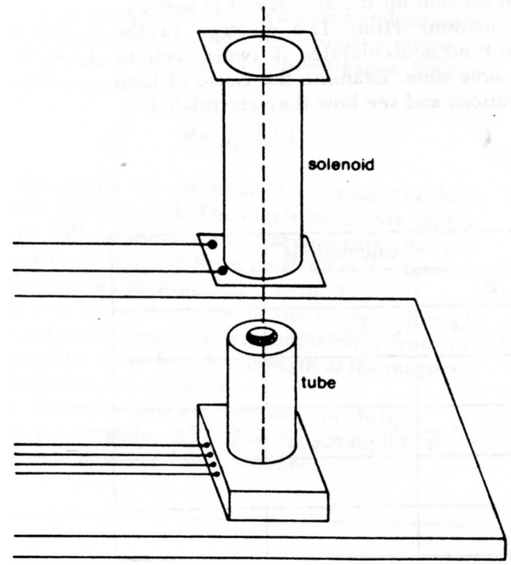

Figure 4

C. Measure the variables.

You are now ready to take data for the measurement of the mass of the electron. The accuracy of your data will determine the accuracy of your results. You will measure *R*, the radius of the curve, by matching the curve of the electrons to a cork. Hold the cork over the top of the tube as shown in Figure 5 and change the current in the solenoid until the curve of the electron paths (refer to Figure 6) is the same as the curve of the cork. The electron paths must match the cork. You can measure the radius of the cork to find the radius of the electron paths.

With the accelerating potential set at about 130 volts, measure one complete set of values of the accelerating potential *V*, the current I through the solenoid, and the radius of curvature *R*. Record their values in Table 1.

Change the accelerating potential to about 190 volts and repeat the measurements. If you have time, you may want to take data using other accelerating potentials as well. Record all data that you take in Table 1.

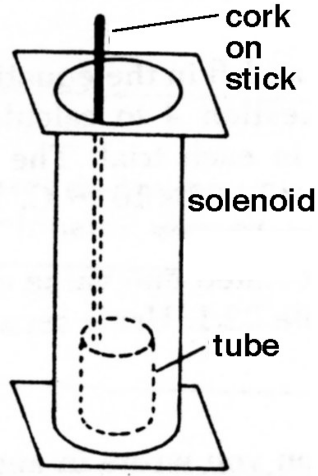

Figure 5

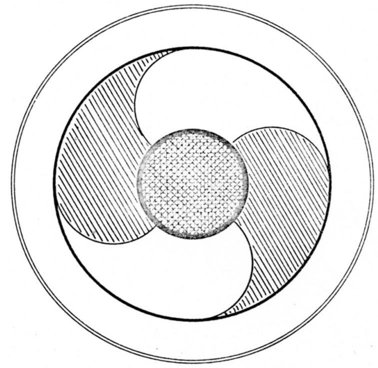
Figure 6

Data Analysis

A. Calculate *B*.

To determine the mass of the electron, you must first determine *B* for each trial. Record these values in Table 1.

Show how you calculated one value of *B* that you entered in Table 1. Use a separate sheet of paper.

B. Calculate *v*.

Use the values of *B*, *V*, and *R* in the equation you wrote in answer to question 4 to calculate the speed of the electrons in each trial. The charge on the electron is $q = 1.602 \times 10^{-19}$ C. Record your values for *v* in the table.

Show how you calculated one value of *v* that you entered in Table 1. Use a separate sheet of paper.

C. Calculate *m*.

You can use the equation you wrote in answer to question 3 to calculate the mass of the electron for each trial. Enter the mass in each case in the table.

Show how you calculated one value of *m* that you entered in Table 1. Use a separate sheet of paper.

D. Calculate the average value of m.

Use all your calculated values of *m* to determine an average value of the mass of the electron.

What is the average value of m?

Look up the best measured value of the mass of the electron in your textbook.

Compare the best value of the mass of the electron with your average value. Calculate percentage difference. Your value of *m* is good if it is less than ten times more or ten times less than the best value. Show your calculation on a separate sheet of paper.

Table 1

	data			calculations		
trial	***V***	***R***	***I***	***B***	***v***	***m***

Error Analysis

Typed and attached.

Conclusion

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Reflection

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