Name Partners Date

Ratio of Mass to Charge for an Electron

Goal

- To build a physical model of how an electron behaves in the presence of electric, magnetic and gravitational fields.
- Use this physical model to design an experiment to measure the charge to mass ratio of an electron as well as the charge on an electron.
- Take a series of measurements using the provided experimental equipment and calculate an experimental value for e/m_e. Use error analysis to make comparisons with the expected value.
- Use statistical methods to determine the charge on an electron from results provided by Millikan's experiment.

A. Introduction

PLEASE COMPLETE SECTION A BEFORE CLASS.

In the late 1800's there was great interest in a phenomenon known as "cathode rays". Cathode rays were observed between metal plates in an evacuated tube across which a large electrical potential had been established. Joseph J.Thomson, a professor of experimental physics at the famous Cavendish Laboratory at Cambridge University, had been studying the properties of electrical discharges in gases. Thomson believed that cathode rays were charged particles (unlike Heinrich Hertz who thought they were waves) and designed an experiment to calculate the charge to mass ratio of what would become known as *electrons.* Figure 1 illustrates the equipment Thomson used in his now famous experiment.

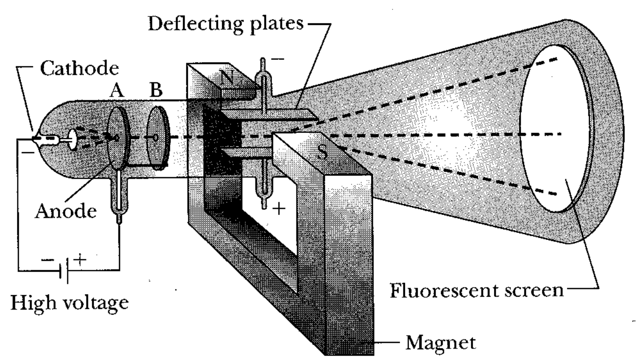

Figure 1. Apparatus of Thomson's cathode-ray experiment

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Equipment

WARNING: Voltages in this experiment can exceed 5,000 Volts. Treat the wires and other electrical conductors with proper respect.

We will use an electron tube that uses a high voltage to impart energy to electrons. As illustrated in Figure 1, the electrons can be forced to change their direction of motion by applying electric and magnetic fields. The electric field is created by a set of plates inside the tube while the magnetic field is created by a set of wire coils through which an electric current passes. Scales inside the electron tube will help us determine the radius of the circle in which the electron moves.

A-1. Write an equation describing the force experienced by an electron in the presence of a magnetic field.

A-2. Write an equation describing the force experienced by an electron in the presence of an electric field between two plates separated by a distance *d*.

A-3. In this experiment, the magnetic and electric fields are perpendicular to each other. Use the equations above to establish a relationship for e/m_e in terms of variables that can be measured.

A-4. Outline an experimental design that will enable you to quantitatively measure the charge to mass ratio of an electron (e/m_e).

A-5. Describe any unknown variables and potential sources of error in your experimental design. Suggest ways to determine unknown variables and minimize the errors in your experiment.

B. The Experiment

In this experiment we will determine e/m_e by using magnetic deflection. If the electron of mass m_e and charge e is at right angles to a magnetic field it will experience a force that constrains it to a circular path.

B-1. Write an equation that describes the force experienced by the electron in this circular path.

B-2. Assume that the electron's energy is kinetic and comes from being accelerated in the electron gun. Write another equation describing the electron's velocity in terms of the accelerating voltage.

B-3. Combine the two equations from B-1 and B-2 to give an equation for e/m_e.

The value of the magnetic field can be determined using:

$$B = \mu_0 NI/2R$$

Where *I* is the current in the coils, *R* is the radius of the coils, *N* is the number of turns (written on the coils) and $\mu_0 = 4\pi\times 10^{-7}$ T M/A.

B-4. For a variety of accelerating voltages, balance the electric and magnetic forces and record the values below. Include errors associated with each instrument.

Accelerating voltage V_a	Coil current I_b (y+)	Coil current I_b (y-)	Average coil current

Table 1. Table of coil currents for a variety of accelerating voltages

B-5. Using your table of values, calculate e/m_e and it's associated error. How does it compare with the currently accepted value of -1.76×10^{11} C/kg?

C. Charge on an Electron

In the previous experiment you have been able to determine a microscopic quantity (e/m_e) by measuring macroscopic variables (voltages and current). An American physicist, Robert Millikan, used a similar approach to determine the charge on an electron in 1911. His famous oil drop experiment gave convincing evidence for a basic quantized electron charge.

The experiment consisted of visual observation of the motion of uncharged and both negatively and positively charged oil drops moving under the influence of gravitational and electric forces. The basic apparatus is illustrated in Figure 2.

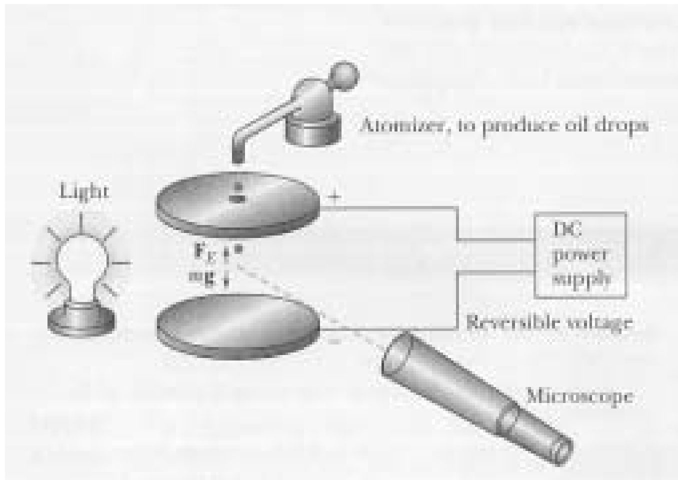

Figure 2. Millikan's oil drop experiment

C-1. Write an equation to describe the gravitational force on an oil drop in this experiment.

C-2. Write an equation to describe the electric force on an oil drop in this experiment.

Stokes Law relates the radius of an oil drop to its terminal velocity. Millikan turned off the electric field and measured the terminal velocity of the oil drop. The mass of the drop can then be determined by knowing the radius *r* and the density ρ of the type of oil used:

$$m = 4/3\pi r3\rho$$

C-3. Use this equation and those you wrote in C-1 and C-2 to give an expression for *q* the charge on the oil drop.

The Millikan oil drop experiment is a very tedious experiment to conduct and we are not asking you to so. Instead, you will analyze some sample data collected by undergraduate students at a university. But first, you need to familiarize yourself with the experimental set up and procedure. The apparatus for the experiment is set up for you to examine. Then, view the footage of the experiment on the videodisc.

Now that you are familiar with the experiment, you are ready to analyze some data. Using the computers provided, open a spreadsheet called "Millikan's oil drop exp.xls" located on the desktop. On the sheet labeled SAMPLE is a table with 30 sample measurements that would be taken while conducting Millikan's oil drop experiment. On the sheet labeled ANALYSIS, 100 sample measurements of q (the charge on an oil drop) have been listed in Column A. We have taken the absolute value of q and put it in Column B as we are only interested in the magnitude of the charge. In Column C $|q|$ has been sorted from lowest to highest value.

Take the sorted values of q and distribute them in the bins provided. Bin marked 1 ranges from 1.0 to 1.19, Bin marked 1.2 ranges from 1.2 to 1.39 and so on. When you have finished, look at the chart labeled HISTOGRAM, it displays the data.

C-4. Using the histogram, how can you determine the charge on an electron from this distribution?

Appendix A

Meter Errors

Moving coil meters = ±2% of full scale deflection (FSD).

Digital meters = ±2% of actual reading.

Combining systematic errors

When multiplying or dividing variables add percentage errors.

$\Delta z/z = \Delta x/x + \Delta y/y$