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Discovering the Charge of an Electron

Analogy of Millikan's Oil-Drop Experiment

Introduction

The electron is an elementary particle of matter having a negative charge. Exactly how much electrical charge does one electron have? In 1911, Robert Millikan (1868–1953) published the results of a series of experiments designed to quantify the charge of an electron. What is amazing about this work is that Millikan determined the charge of a single electron without knowing the number of electrons for which he was gathering data. After all, no one has ever seen an electron! Model Millikan's famous experiment by determining the mass of one BB without weighing any known quantity of BBs.

Concepts

- Electrons
- Electrical charge
- Quantization of energy

Background

To determine the charge of an electron, Millikan used an apparatus that included a chamber with two metal electrode plates. An atomizer was used to spray tiny droplets of oil into the chamber above the top plate. Friction from the atomizer caused some of the oil droplets to pick up a static charge. Millikan also charged more droplets by exposing the chamber to X-rays. As the droplets fell inside the chamber, a few went through a hole in the top plate. Millikan used a small telescope to view the motion of the droplets (see Figure 1). Knowing the density of the oil, the time for one droplet to fall between two reference points, and the force of friction from the air, Millikan determined the mass and acceleration due to gravity for each droplet observed. Before the droplets reached the bottom electrode, the voltage was turned on, creating an electric field between the two electrodes. This caused the negatively charged droplets to be attracted toward the top positive electrode. As he varied the voltage between the plates, Millikan could suspend a single droplet in the air or cause it to rise or fall in the chamber at different rates. By factoring in all forces acting on the droplet, Millikan was able to calculate the total electric charge on the droplet. Yet Millikan did not know how many electrons were contributing to the total charge on the measured droplet. Millikan reasoned that with enough data—that is, by measuring and calculating the total charges for many different oil droplets—he could deduce the charge of a single electron. The smallest *difference* between measured charges should correspond to the electric charge of one electron. In 1923, Millikan received the Nobel Prize in Physics for this work.

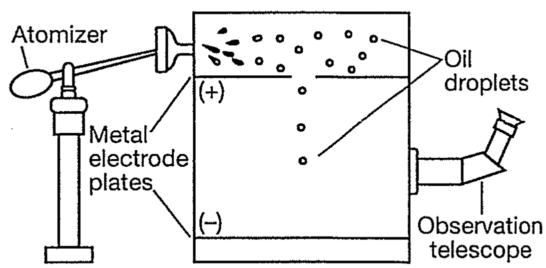

Figure 1.

Experiment Overview

The purpose of this experiment is to determine the mass of a single BB without weighing any known number of BBs. Magnets of varying sizes will be used to attract different unknown quantities of BBs. These unknown quantities will be weighed and the reasoning employed by Millikan in his oil-drop experiment will be used to determine the mass of one BB.

Pre-Lab Questions

1. An *analogy* in science is an activity or experiment that models or simulates a real-world experiment. Read through the *Background* section and the complete *Procedure*. What part of this experiment is analogous to the electrons in Millikan's Oil-Drop Experiment? What is analogous to the oil droplets? The total charge on a droplet?
2. How is the procedure in this experiment similar to Millikan's procedure? How is it different?

Materials

Balance, centigram
BBs, 100 in a medium-size weighing dish
Forceps, plastic
Magnetic strip, 20 cm
Ruler, metric
Scissors
Weighing dish, small

Safety Precautions

The materials in this experiment are considered nonhazardous. Immediately pick up any BBs that may have rolled onto the floor to prevent a person from slipping on them. Wash hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines.

Procedure

1. Obtain scissors, a metric ruler, and a 20-cm magnetic strip.
2. Measure and cut one 40-mm piece from the magnetic strip. Set this large piece aside for step 14.
3. Cut a second piece from the magnetic strip that is 20 mm long.
4. Cut the remainder of the magnetic strip into 13 pieces of varying sizes ranging from 5 mm to 20 mm long. Try to cut as many different sizes as possible. The smallest piece should be no less than 5 mm.
5. Obtain a weighing dish with 100 BBs, a smaller weighing dish, and plastic forceps.
6. Choose one magnetic piece at random (not the largest piece) and drop it into the dish of BBs.
7. Use the forceps to move the piece around and turn it over a few times until the magnet is covered with BBs. *Note:* The BBs may only be attracted to one side of the magnet.
8. Place the small weighing dish on the balance and tare the balance to zero.
9. Gently pick up the magnet and BBs with the forceps, being careful so no BBs are dislodged from the magnet. Cup one hand under the magnet to prevent any BBs from falling onto the floor.
10. Transfer the BBs into the small weighing dish by gently brushing them off the magnet (see Figure 2).
11. Record the total mass of the BBs attracted to Magnet Piece 1 under *Mass of BBs* in the data table. *Do not count the BBs.*
12. Pour the BBs from the small weighing dish back into the larger weighing dish.
13. Repeat steps 6–12 thirteen more times, each times using a different size of the small magnetic strips cut in step 4. Try to select the magnet pieces at random; that is, do *not* test them in order from smallest to largest.

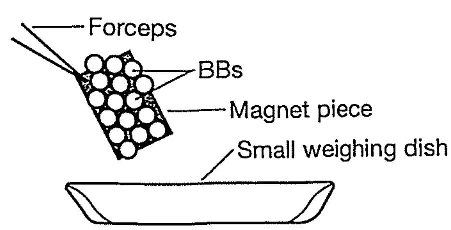

Figure 2.

14. Repeat steps 6–11 using the 40-mm magnet piece from step 2, only this time **leave the BBs in the small weighing dish** after recording the mass. Remove the small dish with the BBs from the balance and set it aside for future reference.
15. Complete the data table according to the instructions on the worksheet and answer the questions.

Name: ______________________

Discovering the Charge of an Electron Worksheet

Data Table

Magnet Piece	Mass of BBs (g)	Sorted Mass (g)	Unique Masses (g)	Difference in Mass (g)
1				—
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15 (40-mm)				Avg.

Post-Lab Analysis and Calculations

1. Arrange the measured masses of BBs into the *Sorted Mass* column in *descending* order, starting with the largest recorded mass and ending with the smallest.
2. Some of the masses in the *Sorted Mass* column may be the same or nearly the same (within a few hundredths of a gram of each other).
   a. Average the masses that are nearly the same. For example, masses of 3.12, 3.11, and 3.10 grams would average to 3.11 g.
   b. Record only the unique masses and the average masses of those that are nearly the same in the *Unique Masses* column of the data table. *Note:* This column will have fewer than 15 data points.
3. Subtract each unique mass from the one just above it in the *Unique Masses* column and record each difference in the last column of the data table. Again, this *Difference in Mass* column will have fewer than 15 data points.
4. Note the smallest value in the *Difference in Mass* column between any two samples of BBs. If several of the differences in mass are the same or nearly the same as the smallest difference, find the average smallest difference and record this value at the bottom of the last column. What does this difference represent?
5. Using the average smallest difference in mass calculated above and the recorded mass for the BBs from the final 40-mm magnet piece, predict the number of BBs that were attached to the largest magnet. Record your prediction below.
   Predicted number of BBs from largest magnet _________
6. Count and record the number of BBs in the weighing dish from step 14 of the *Procedure*.
   Actual number of BBs from largest magnet _________

Post-Lab Questions *(Answer on a separate sheet of paper.)*

7. How did the predicted number of BBs compare to the actual number from the largest magnet? What possible sources of error are in this procedure?
8. One could easily determine the mass of a single BB by weighing it or by weighing a known number and dividing the total mass by the number of BBs weighed. Why couldn't Robert Millikan determine the charge of a single electron in a similar manner?
9. The predicted number of BBs was checked with the actual number of BBs attached to the largest magnet. Millikan could not verify his results in the same way. Give examples of other scientific research that depends on supporting evidence without the ability to verify results in such a concrete way.