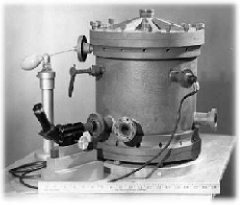
SPH4U UNIVERSITY PHYSICS

GRAVITATIONAL, ELECTRIC, & ... FIELDS

☞ The Millikan Oil Drop Experiment (P.362-364)

Elementary Charge?

At the start of the 20th century physicists still had many questions about the charge of fundamental particles. A big question was, is there a smallest unit of charge that nature will allow, and if so, what is the value of this charge? So, in 1909, physicist Robert Millikan set out to examine the existence of this elusive fundamental charge using a series of experiments.



Elementary Charge?

NOTE!

*Millikan hypothesized that an **elementary charge**, e, the smallest unit of charge in nature, did exist, and that the charge of the electron equalled this elementary charge.*

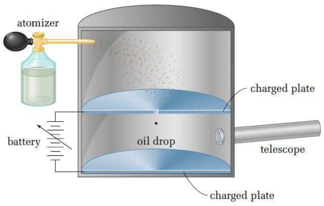
Elementary Charge?

MILLIKAN

- was trying to answer two fundamental questions:
  - ① Is there a smallest unit of charge?
  - ② What is the value of this charge?
- hypothesized:
  - an elementary charge did exist
  - $q_{electron}$ = elementary charge

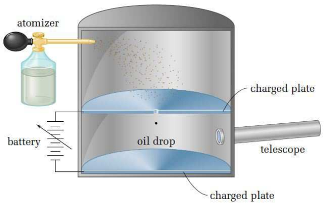
Millikan Oil Drop Experiment

To create charged objects, Millikan used a fine mist of oil droplets sprayed from an atomizer. The droplets picked up charges due to friction when sprayed from the atomizer. Millikan further hypothesized that the amount of charge any one drop picked up would be a whole-number multiple of the fundamental charge.



Millikan Oil Drop Experiment

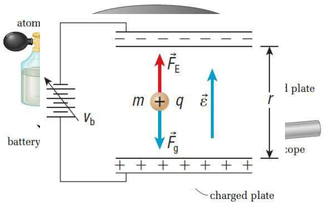
To measure the charge on a drop, Millikan used a device called an electrical microbalance. He allowed the oil drops to fall into a region between two oppositely charged parallel plates. The charges on the plates mean that there is an electric field in the space between the plates, which creates a potential difference between the top plate and the bottom plate.



Millikan Oil Drop Experiment

NOTE!

The plates were connected in such a way that the magnitude of the electric field and, therefore, the electric force on the droplets, could be adjusted. By adjusting the electric force to balance the downward gravitational force, Millikan could bring a charged drop of oil to rest in the region between the plates.

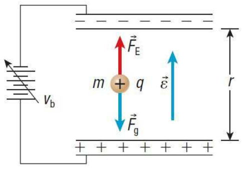


Millikan Oil Drop Experiment

We can understand how Millikan used the electrical microbalance to determine the charge on an oil drop by comparing the electric and gravitational forces. For example:

$$F_E = F_g$$

$$q\varepsilon = mg \quad \text{but} \quad \varepsilon = \Delta V/\Delta d$$



Millikan Oil Drop Experiment

NOTE!

To measure the mass of a drop, Millikan simply switched off the electric field and observed the final speed of the drop as it fell onto the bottom plate. From the final speed, he could calculate the mass of the drop if he accounted for both the gravitational force and the force due to air friction. With this information, he could determine the charge on the drop.

$$q = \frac{mg\Delta d}{\Delta V}$$

Millikan Oil Drop Experiment

Millikan repeated his experiment many times, balancing a drop, measuring the voltage, letting the drop fall, and measuring its final speed. When he analyzed the data, he discovered the hypothesized pattern. The values of the charges he measured were whole-number multiples of some smallest value, and no drops had less charge than this value. Millikan concluded that this charge value equalled the elementary charge of the electron.

NOTE!

Later experiments by other researchers confirmed Millikan's results and improved the accuracy of his findings. The current accepted value of the elementary charge e is:

$$e = 1.602 \times 10^{-19}\text{ C}$$

Millikan Oil Drop Experiment

MILLIKAN'S OIL DROP EXPERIMENT

- confirmed the existence of the elementary charge ($e = 1.602 \times 10^{-19}$ C)

$$q = \frac{mg\Delta d}{\Delta V}$$

where q is the charge on the oil drop (C)
m is the mass of the oil drop (kg)
g is gravitational field strength (N/kg)
Δd is the separation between the parallel plates (m)
ΔV is the potential difference between the plates (V)

Millikan Oil Drop Experiment

PRACTICE

1. Calculate the charge on a small sphere with an excess of 3.20×10^{14} electrons. (Recall that q = Ne)

   $q = -5.12 \times 10^{-5}$ C (-ve because there is an excess of electrons)

Millikan Oil Drop Experiment

PRACTICE

2. Calculate the force of repulsion between two plastic spheres that are located 110 cm apart. Each sphere has a deficit of 1.2 x 10^8 electrons.

   F_E = 2.7 x 10^{-12} N

Millikan Oil Drop Experiment

PRACTICE

3. Two horizontal plates in a Millikan-like apparatus are placed 16.0 mm apart. An oil drop of mass 3.00 x 10^{-15} kg remains at rest between the plates when a potential difference of 420 V is applied across the plates, the upper plate being positive. Calculate the:
   (a) net charge on the oil drop,
   (b) sign of the charge on the oil drop, and
   (c) number of excess or deficit electrons on the oil drop.

   (a) q = 1.12 x 10^{-18} C
   (b) negative (since upper plate was positive)
   (c) 7 excess electrons

Millikan Oil Drop Experiment

PRACTICE

4. A pair of horizontal metal plates are situated in a vacuum and separated by a distance of 1.8 cm. What potential difference would need to be connected across the plates in order to hold a single electron suspended at rest between them?

   ΔV = 1.0 x 10^{-12} V

Problems with Millikan Oil Drop Experiment?

While Millikan was successful in discovering and measuring the fundamental charge, there was some controversy with his experiment.

① *He expressed the time for the oil drops to fall/rise to an accuracy of 1/1000 of a second using a stopwatch (which was almost impossible in the early 1900s).*

② *The extremely small drops bumped into one another which not only affected their rate of fall but those of other oil drops.*

③ *Millikan disregarded a large set of oil drop data in his experiments that did not agree with his hypothesis.*

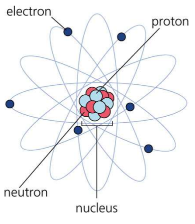
Problems with Millikan Oil Drop Experiment?

MILLIKAN'S OIL DROP EXPERIMENT (continued …)

- while successful, there was controversy with Millikan's procedure:
  - he expressed rise/fall times to an accuracy of 1/1000 which was almost impossible in the early 1900s
  - the small drops bumped into one another which not only affected their rate of fall but those of other oil drops
  - he disregarded data that did not agree with his hypothesis

Charge of a Proton

The elementary charge of a proton is equal in magnitude to the value of the electric charge of the electron. Careful experimentation has consistently shown that the two particles have charges that are equal in magnitude. This result is actually a surprise, because the electron and proton have very little else in common, including their masses and the roles they play in the structure of matter.

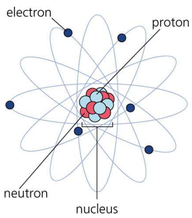


Charge of a Proton

PRACTICE

5. An electron and a proton are situated in an electric field.
   (a) Will the magnitude of the electric force on each be equal? Explain.

   (a) yes – $F_e \propto q$

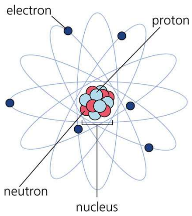


Charge of a Proton

PRACTICE

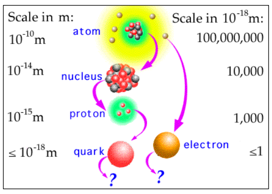
5. An electron and a proton are situated in an electric field.
   (b) Will the magnitude of the acceleration on each be equal? Explain.

   (b) no – $a \propto 1/m$ (in fact, the electron will have a greater acceleration b/c it has a smaller mass)



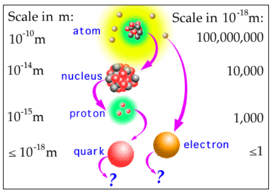
Charge of a Proton

Furthermore, physicists think of the electron as a fundamental particle with no inner workings, but they now view the proton as a combination of more fundamental particles called ***quarks****. The proton consists of three quarks, all of which have charges that are either exactly 1/3 or 2/3 of the elementary charge.*



Charge of a Proton

Despite having fractional charges, though, no experiment has detected any combination of quarks in nature that have a total charge whose magnitude is less than e. For this reason, physicists still refer to e as the elementary charge.



Charge of a Proton

In fact, every subatomic particle that researchers have so far detected has a charge whose magnitude is equal to a whole-number multiple of e. Researchers also believe that the amount of charge in an isolated system is conserved like energy. Unlike energy, electric charge does not come in different types and cannot change from one form to another. No interaction can destroy or create electric charge, and the total electric charge of the universe remains constant.

Activity: The Millikan Exp. (Inv.7.6.1/P.367)

BACKGROUND

In Part A of this activity, you will model the Millikan oil drop experiment. In Part B, you will use given data to test your predictions from Part A.

INSTRUCTIONS

A. Follow procedure steps 1-9.

B. Answer analysis questions (a)-(f)

C. Answer Q.4-6/P.365

NOTE!

See next page.

Activity: The Millikan Exp. (Inv.7.6.1/P.367)

NOTE!

Part A
- list the masses from smallest to largest before you start calculating differences
- you will not need the mass of the empty container
- Step 6 - graph the "whole difference" (step 5) on the x-axis
  - graph "mass" (**not** mass difference) on the y-axis

Part B
- the distance (Δd) between the plates is 5.0 mm
- Step 9 - recall $q = mg\Delta d/\Delta V$
- (b)
  - similar to A
  - find the differences between the charges, then find the smallest difference, then divide each charge by ...
  - graph the "whole difference" on the x-axis
  - graph "charge" on the y-axis

Activity: The Millikan Exp. (Inv.7.6.1/P.367)

SAMPLE DATA

Bag 1 - 31.5g
Bag 2 - 61.5g
Bag 3 - 79.5g
Bag 4 - 49.5g
Bag 5 - 86.7g
Bag 6 - 44.1g
Bag 7 - 18.3g
Bag 8 - 143.0g
Bag 9 - 121.5g
Bag 10 - 229.5g