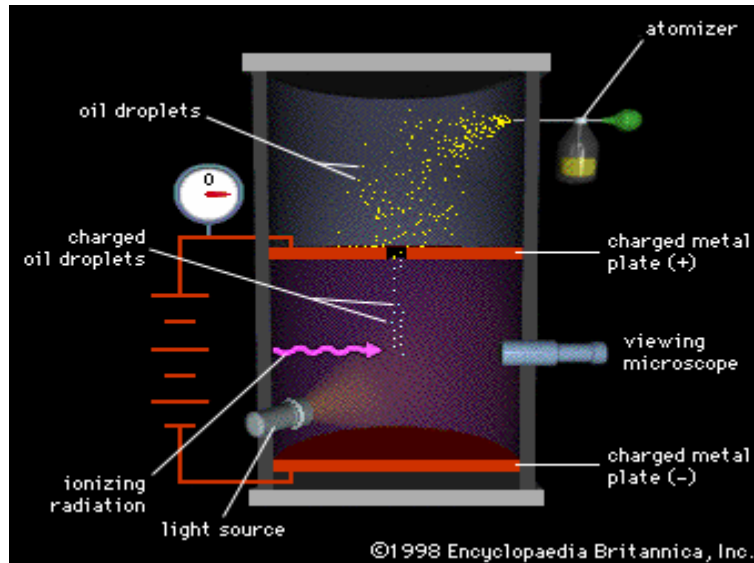


MILLIKAN OIL DROP EXPERIMENT

INTRODUCTION

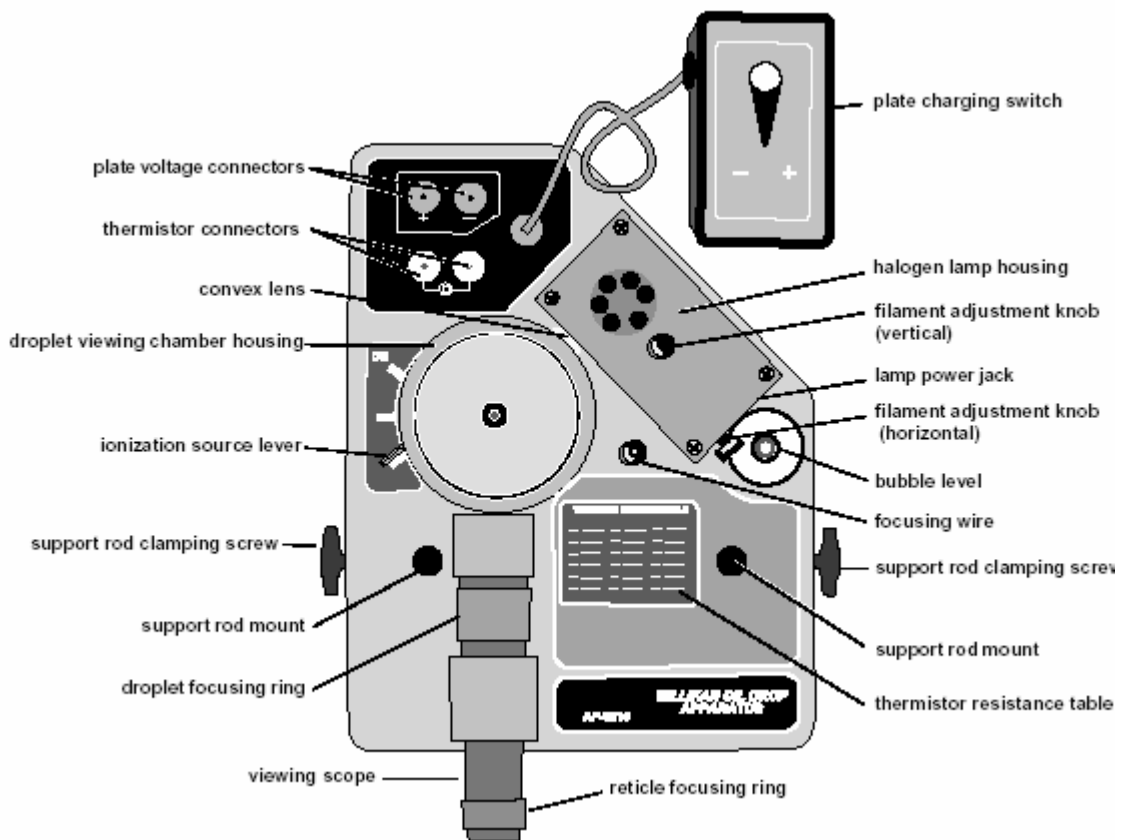
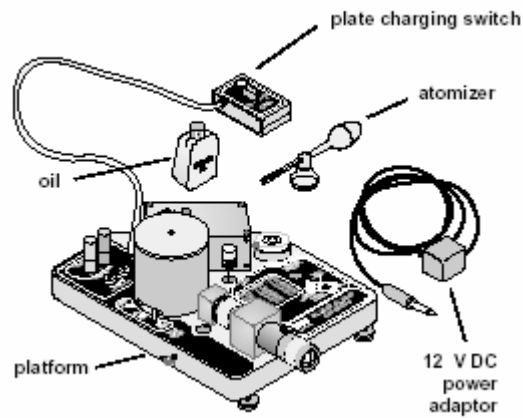
In this experiment you will experimentally determine the quantum nature of charge. Robert Millikan was awarded the Nobel Prize in physics in 1923 for this brilliant experiment. A simplistic schematic of his apparatus is shown below.



A spherical drop of oil, falling through a viscous medium like air, will quickly reach a constant velocity. When it reaches this equilibrium state, the viscous force is balanced by other forces acting on the drop, such as gravity, buoyant forces from the air, electrical forces, etc. In this experiment an electrical force of varying magnitude is introduced to change the motion of the falling drop by an ionization source. By measuring the velocity of the oil drop under different conditions the amount of charge on the drop may be determined. If the charge on the drop is an integer multiple of the fundamental unit of charge (the electron), then one will be able to confirm the quantization of charge.

EQUIPMENT

1. Millikan Oil Drop Apparatus (see diagrams below)
2. High voltage power supply (0-500VDC)
3. Digital multimeter
4. 4 banana leads
5. Stopwatch
6. Micrometer
7. Barometer



Millikan Oil Drop Apparatus

THEORY

The charge carried by an oil droplet can be obtained by analyzing the forces acting on the drop under different conditions. Figure 1 shows the forces acting on the drop when it is falling in air and has reached its terminal velocity.

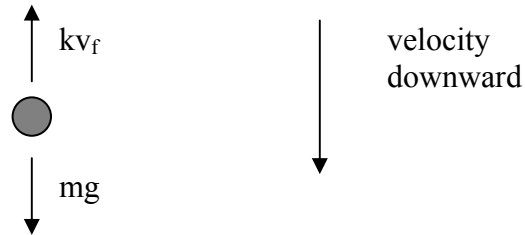


Figure 1

In this experiment the terminal velocity of the drops is reached in a few milliseconds. Applying Newton's 2nd Law to the falling oil drop yields:

$$kv_f - mg = 0 \quad (\text{E-field off}) \quad (1)$$

Figure 2 shows the forces acting on the drop when it is rising under the influence of an electric field.

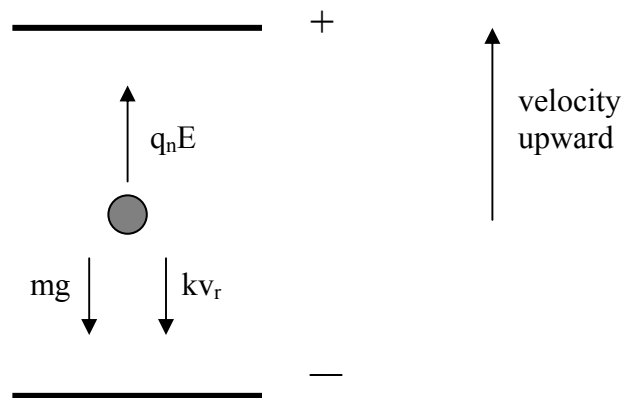


Figure 2

Applying Newton's 2nd Law again we have:

$$q_n E - mg - kv_f = 0 \quad (\text{E-field on}) \quad (2)$$

In Equations (1) and (2) we have neglected the buoyant force exerted by the air on the droplet. This is reasonable since the density of air is only about one-thousandth that of oil. The equations can now be used to obtain an expression for the charge q_n on the oil drop. The result is:

$$q_n = \frac{mg(v_f + v_r)}{v_f E} \quad (3)$$

The electric field in the region of the oil drop is produced by two parallel plates maintained at a potential difference V and separated by a distance d . The relation is given by $E = V/d$. Thus, equation (3) becomes:

$$q_n = \frac{mgd(v_f + v_r)}{v_f V} \quad (4)$$

The mass ' m ' of the oil drop is given by:

$$m = (4/3)\pi a^3 \sigma \quad (4)$$

where ' a ' is the radius of the drop and ' σ ' is the density of the oil drop.

To calculate the radius of the oil drop you will need to use Stokes' Law, which relates the radius of a spherical falling body in a viscous medium to its terminal velocity. According to Stokes' Law the viscous force on a spherical falling body in a viscous medium is given by:

$$F = 6\pi\eta av_f \quad (5)$$

where η is the coefficient of viscosity, which in our case will be the viscosity of air. Using this expression and applying Newton's 2nd Law to a falling oil drop under the influence of the viscous and buoyant force, one can show that the radius of the oil drop is:

$$a = \sqrt{\frac{9\eta v_f}{2g(\sigma - \rho)}} \quad (6)$$

Where σ is the oil drop density, ρ is the density of air, v_f is the falling velocity, g is the acceleration of gravity, and η is the coefficient of viscosity air. Here we have included the density of air for better accuracy.

Stoke's Law becomes incorrect when the velocity of fall of the droplets is less than 0.1 cm/s. Droplets having this and smaller velocities have radii, on the order of 2 μm , comparable to the mean free path of air molecules, a condition which violates one of the assumptions made in deriving Stoke's Law. Since the velocities of the droplets used in this experiment will be in the range of 0.01 to 0.001 cm/s, a correction factor must be included in the expression for e_n . This factor is:

$$\left(\frac{1}{1 + b/pa}\right)^{3/2} \quad (7)$$

where b is a constant, p is the atmospheric pressure, and a is the radius of the drop as calculated from equation (5). Using the correction factor, the charge on the droplet is now given by:

$$q_n = \frac{mgd(v_f + v_r)}{v_f V} \left(\frac{1}{1 + b/pa}\right)^{3/2} \quad (8)$$

Equation (8) contains measurable quantities and constants and can now be used to measure the charge on an oil droplet. The following is a list of the variables and constants that are used in equation (8).

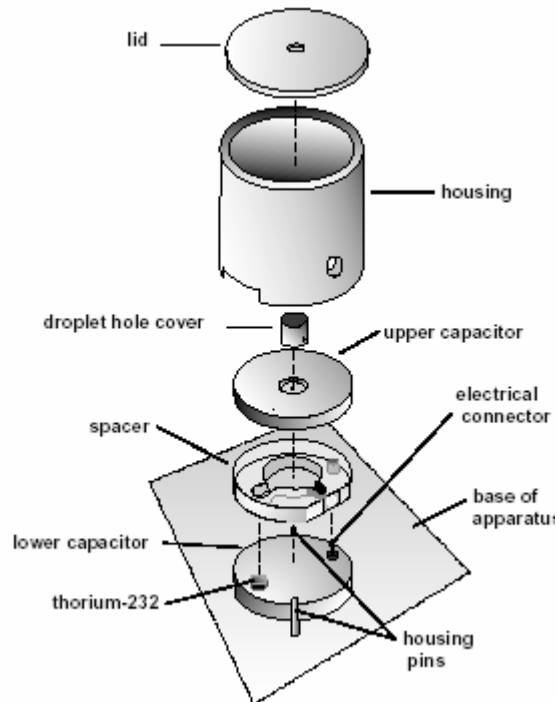
- e_n = The charge, in coulombs, carried by the droplet
- d = Separation of the plates in the condenser in meters
- σ = Density of oil in kg/m^3 (886 kg/m^3)
- ρ = Density of air in kg/m^3 (See Appendix C)
- g = Acceleration of gravity in m/s^2
- η = Viscosity of air in poise (Ns/m^2) (See Appendix A)
- b = Constant, equal to $8.20 \times 10^{-3} \text{ Pa} \cdot \text{m}$
- p = The barometric pressure in Pascals (Pa)
- a = The radius of the drop in meters

v_f = The fall velocity of the oil droplet in m/s
 v_r = The rise velocity of the oil droplet in m/s
 V = The potential difference across the plates in volts
 m = Mass of oil droplet in kg

EQUIPMENT SETUP

Measuring Plate Separation

1. Place the Millikan Oil Drop apparatus on a level, solid table.
2. Level the apparatus by using the bubble level as a reference and turning the leveling screws on the platform.
3. Disassemble the droplet viewing chamber by lifting the housing straight up and then removing the upper capacitor plate and spacer plate (see Figure 3).
4. Measure the thickness of the plastic spacer with the micrometer. Be sure not to include the raised rim of the spacer in your measurement.



Droplet Viewing Chamber (Figure 3)

Focusing the Viewing Scope

1. Reassemble the plastic spacer and the top capacitor plate onto the lower capacitor plate. Replace the housing, aligning the holes in its base with the housing pins (see Figure 3).
2. Unscrew the focusing wire from its storage place on the platform and carefully insert it into the hole in the center of the top capacitor plate (see figure 4).

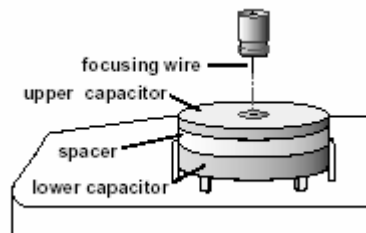


Figure 4

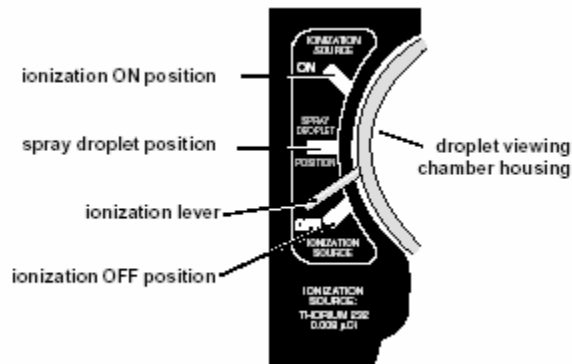
3. Connect the 12 VDC transformer to the lamp power jack in the halogen lamp housing.
4. Bring the reticle into focus by turning the reticle focus ring.
5. View the focusing wire through the viewing scope, and bring the wire into sharp focus by turning the droplet-focusing ring.

Focusing the Halogen Filament

1. Adjust the horizontal filament adjust knob. The light is best focused when the right edge of the wire is brightest.
2. While viewing the focusing wire through the viewing scope, turn the vertical filament adjustment knob until the light is brightest on the wire in the area of the reticle.
3. Return the focusing wire to its storage location on the platform.

Ionization Source Lever (used to change the charge on oil drop)

1. When the lever is at ionization **OFF** position, the ionization source is shielded on all sides by plastic, so that virtually no alpha particles enter the area of the drops.
2. At the **ON** position, the plastic shielding is removed and the drop area is exposed to the ionizing alpha particles emitted from Thorium-232.
3. At the Spray Droplet Position the chamber is vented by a small air hole that allows air to escape when oil drops are being introduced to the chamber.



Ionization Source Lever Settings

Plate Charging Switch

The plate-charging switch has three positions:

1. **TOP PLATE -** : negative binding post is connected to the top plate.
2. **TOP PLATE +** : positive binding post is connected to the bottom plate.
3. **PLATES GROUNDED**: plates are disconnected from the high voltage supply and are electrically connected.

Adjusting and Measuring the Voltage

1. Connect the high voltage DC power supply to the plate voltage connectors and adjust to deliver about 450 V.
2. Use the multimeter to measure the voltage delivered to the plates.

Determining the Temperature of the Droplet Viewing Chamber.

1. Connect the multimeter to thermistor connectors and measure the resistance of the thermistor. Use the Thermistor Resistance Table located on the platform to find the temperature within the droplet-viewing chamber.
2. The temperature in the chamber may rise after prolonged exposure to the light. Therefore, you should also measure the temperature at the end of the lab to make you are recording the correct temperature.

EXPERIMENTAL PROCEDURE

1. Complete the reassembly of the droplet viewing chamber by placing the droplet hole cover on the top capacitor plate and then placing the lid on the housing (see figure 3).
2. Measure and record the plate voltage and the thermistor resistance (temperature).

Introducing the droplets into the chamber

1. Put non-volatile oil of known density into the atomizer.
2. Prepare the atomizer by rapidly squeezing the bulb onto a paper towel until oil is spraying out.
3. Make sure the tip of the atomizer is pointing down.
4. Move the ionization source lever to the **Spray Droplet Position** to allow air to escape from the chamber during introduction of droplets into the chamber.
5. Place the tip of the atomizer into the hole on the lid of the droplet-viewing chamber.
6. While observing through the viewing scope, squeeze the atomizer bulb with one quick squeeze. Then squeeze it slowly to force the droplets through the hole in the droplet hole cover, through the droplet entry hole in the top capacitor plate, and into the space between the two capacitor plates.
7. When you see a shower of drops through the viewing scope, move the source lever to the **OFF** position.

Selection of the Drop

1. From the drops in view, select a droplet that falls slowly (about 0.02 - 0.005 mm/s) when the plate charging switch is in the "**Plates Grounded**" position (no E-field) and has at least one negative charge (changes direction when plates are charged). The distance between major reticle lines is 0.5 mm.

Hint: A drop that requires about 15 s to fall the distance between the major reticle lines will approximately rise the same distance, under the influence of an electric field (1000V/cm), in the following times with the following charges: 15s -1 excess electron; 7s - 2 excess electron; 3s - 3 excess electron.

2. When you find an appropriately sized and charged oil droplet, fine-tune the focus of the viewing scope. The oil droplet is in best focus for accurate data collection when it appears as a pinpoint of bright light.

Measuring the Rise and Fall Times of the Oil Droplet

1. Measure the rise (plates charged) and fall (plates not charged) velocities of the selected droplet 10 times. Maneuver the droplet as needed using the plate voltage switch.

Hint: The greatest accuracy of measurement is achieved if you time from the instant the oil drop passes behind the first major reticle line, to the instant the drop passes behind the second major reticle line. (These lines are 0.5 mm apart)

2. Calculate the charge on the droplet. If the result yields that the charge on the droplet is greater than 5 excess electrons, you should repeat the procedure for slower moving droplets.
3. Repeat steps (1) and (2) for **one additional different drop.**

ANALYSIS

1. Prove that the radius of the oil drop is given by equation (6):

$$a = \sqrt{\frac{9\eta v_f}{2g(\sigma - \rho)}}$$

2. Make a data table with the fall and rise distances and times for each oil droplet.

3. Label and show calculations for:

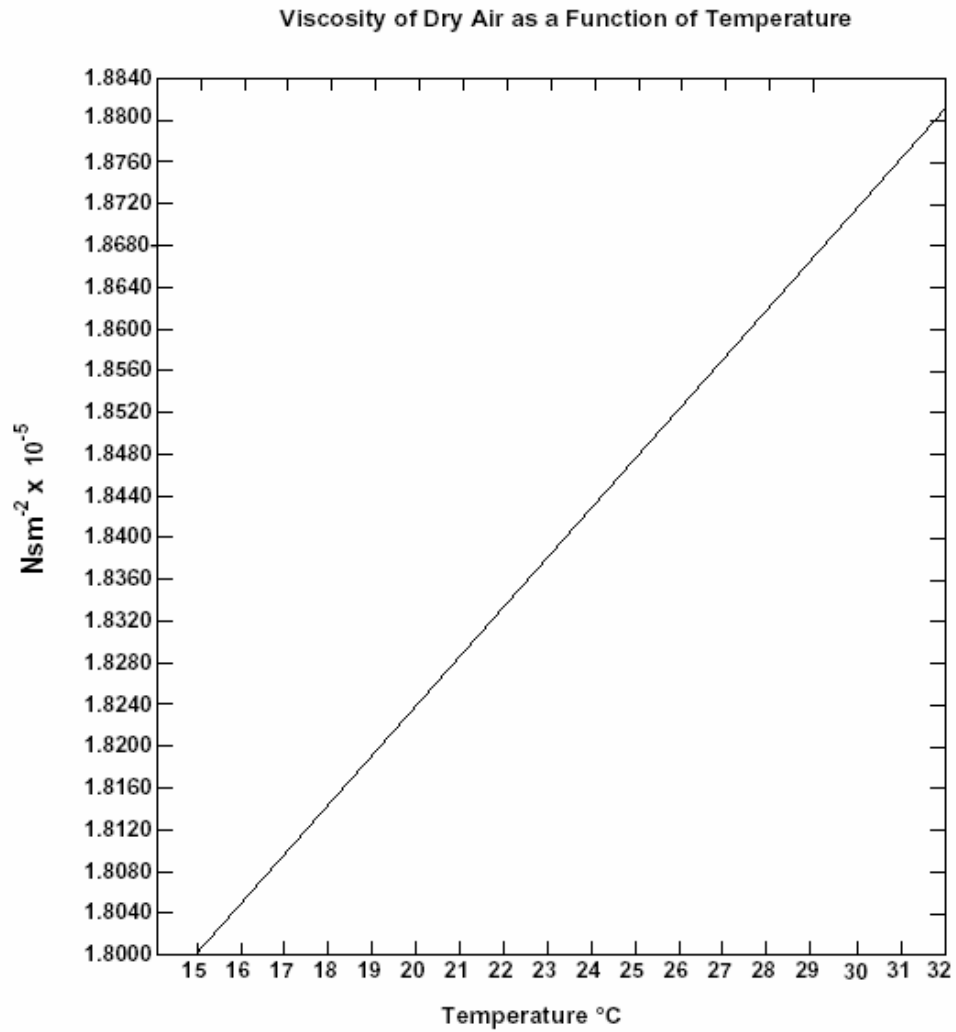
- a) $(v_r)_{\text{average}}$ = average rise velocity
- b) $(v_f)_{\text{average}}$ = average fall velocity
- c) ρ = density of air
- d) a = radius of drop
- e) m = mass of drop
- f) $\left(\frac{1}{1 + b/pa}\right)^{3/2}$ = correction factor
- g) q_n = charge on oil drop

4. Include a table like the following in your report:

| drop | d | σ | ρ | g | η | b | p | a | $V_r(\text{ave})$ | $V_f(\text{ave})$ | V | m | q_n |
|------|---|----------|--------|---|--------|---|---|---|-------------------|-------------------|---|---|-------|
| 1 | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | |

5. Using the accepted value for the charge on an electron, calculate the number of electrons in each oil drop.
6. Comment on sources or errors involved in the experiment.
7. Did this experiment prove the quantization of charge? Explain.

Appendix A: Viscosity of Dry Air as a Function of Temperature*



Appendix B:

Millikan Oil Drop Apparatus Thermistor Resistance at Various Temperatures

| THERMISTOR RESISTANCE TABLE | | | | | |
|------------------------------------|---------------------------|-----------|---------------------------|-----------|---------------------------|
| °C | X 10⁶ Ω | °C | X 10⁶ Ω | °C | X 10⁶ Ω |
| 10 | 3.239 | 20 | 2.300 | 30 | 1.774 |
| 11 | 3.118 | 21 | 2.233 | 31 | 1.736 |
| 12 | 3.004 | 22 | 2.169 | 32 | 1.700 |
| 13 | 2.897 | 23 | 2.110 | 33 | 1.666 |
| 14 | 2.795 | 24 | 2.053 | 34 | 1.634 |
| 15 | 2.700 | 25 | 2.000 | 35 | 1.603 |
| 16 | 2.610 | 26 | 1.950 | 36 | 1.574 |
| 17 | 2.526 | 27 | 1.902 | 37 | 1.547 |
| 18 | 2.446 | 28 | 1.857 | 38 | 1.521 |
| 19 | 2.371 | 29 | 1.815 | 39 | 1.496 |

Appendix C: Density of Air

$$\rho = \rho_0 \frac{P}{760} \frac{273.16}{T}, \text{ where } \rho_0 = \text{density of air at } 0^\circ\text{C, } 1 \text{ ATM} = 1.2929 \text{ kg/m}^3$$