Millikan Oil-drop experiment

(a) Demonstrate that electric charge only comes in discrete units " the quantization of charge"
(b) Measure the intrinsic charge of the electron (the smallest discrete unit of charge) *e.*

In 1911 the American physicist Robert A. Millikan (1868 - 1953) reported convincing evidence for an accurate determination of the electron's charge. For this work and later research on the photoelectric effect, Millikan received Nobel Prize in 1923. Historically, this experiment ranks as one of the greatest experiments of modern physics.

Danger! Before making any adjustment on the sample chamber (capacitor's plates), the high voltage switch should be off.

- **Note that the droplet falling in the field-free space rises in the microscopic image and the droplet rising in the presence of the electric field falls in the microscopic image.**

Useful constants and data about our apparatus:

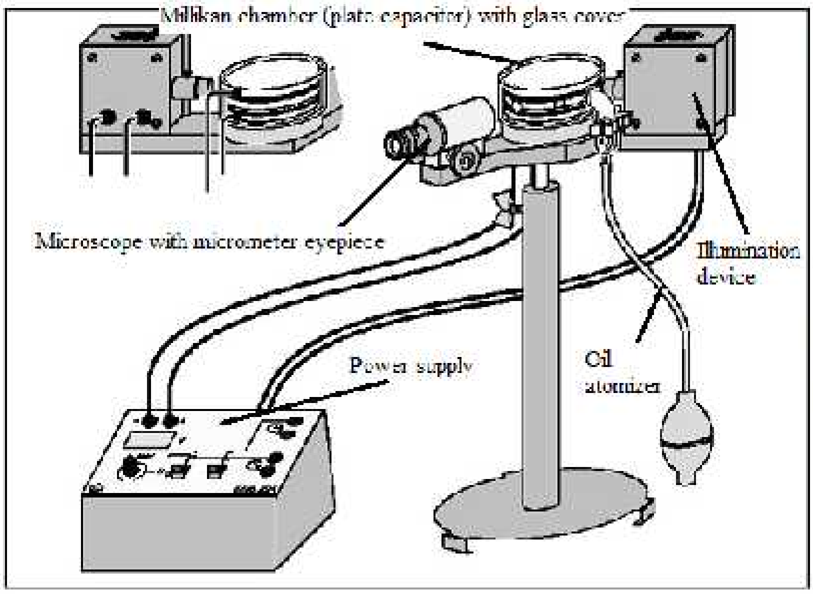
Distance between electric field capacitor plates: $d = 6\ (\pm 0.05)\, mm$.

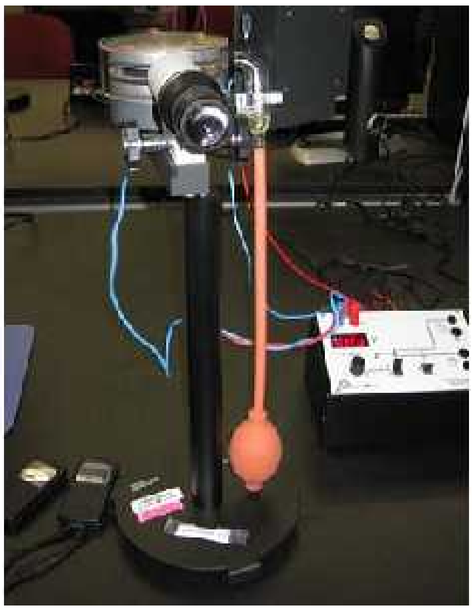
Density of the Oil: $° = 874\ \frac{kg}{m^3}$, (: $° = 877\ \frac{kg}{m^3}$ $(at\ 15\,^oC)$; $° = 871\ \frac{kg}{m^3}$ $(at\ 25\,^oC)$; .)

Coefficient of viscosity of air: $¦ = 1.86\times 10^{-5}\ \frac{N}{m^2\, s}$

Acceleration due to gravity: $g = 9.81 \frac{m}{s^2}$

Accepted value of magnitude of the electron's charge: $q = 1.6\times 10^{-19}\ C$





Millikan oil drop apparatus

- The Millikan power supply: This supply does two things. It supplies to the power to the light (in the black housing on the stand that illuminates the oil drop chamber), and it applies the electric potential difference to the capacitor plates.
- The Millikan oil drop chamber has two metal capacitor plates separated by about 6 mm. There are also two small holes on the right hand side where oil drops can be admitted. Right by them is the atomizer, which is attached to a rubber bulb.

- There is a lamp on the right hand side (powered by the power supply) that shines light into the chamber.
- The telescope is used to view the droplets.
- Verify that the connections from the power supply to the capacitor plates are hooked up so that the positive side (red lead) is on the top and the ground side (blue lead) is on the bottom.

Theory and evaluation

The method to find the charge on an oil drop:

(i) Measure the fall velocity v_1 of a droplet in the free space (at zero voltage) and

(ii) the rise velocity v_2 of same droplet at a definite voltage (say 500 volt)

(i) The forces acting on the drop falling freely with terminal (constant velocity) velocity (v_1) in zero electric field as shown in figure 1.

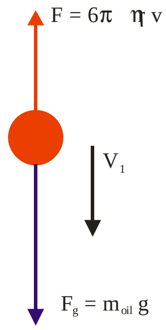


Figure 1. The force on a droplet falling through a field free space with terminal velocity (v_1).

The downward force of the gravitational field: $F_g = m_{oil}\, g$

The mass of the drop can be determined by knowing the radius r and density ρ of the type of the oil used in the experiment: $\rho = \frac{m}{V}$, The drop is spherical in shape so its volume is $V = \frac{4}{3}\pi r^3$, so mass, $m = \frac{4}{3}\pi r^3 \rho$

$\therefore F_g = \frac{4}{3}\pi r^3 \rho\, g$

- When an oil drop falls downward through the air, it experiences a frictional force F_d proportional to its velocity due to the air's viscosity. The upward dragging force (Stoke's law).

Stoke's law: At sufficient low speeds, the drag force F_d on a sphere of radius r, traveling with speed v through a viscous medium of viscosity η, is given by Stoke's law,

$$F_d = -6\pi \eta\, r\, v$$

Where the minus sign indicates that the direction of the drag force is opposite to the direction of the velocity. In this experiment, the viscus medium is air $\left(\eta = 1.86\times10^{-5}\,\frac{N}{m^2\,s}\right)$.

$\therefore F_g - F_d = ma \Rightarrow \frac{4}{3}\pi r^3 \rho\, g - 6\pi \eta\, r\, v_1 = 0$

$$\Rightarrow r = \sqrt{\frac{9\eta\, v_1}{2\rho\, g}} \qquad (1)$$

(ii) The forces on a droplet moving upward with the terminal velocity (v_2) under the influence of an electric field strength (E) are shown in figure 2 (b).

The magnitude of the electric field $\vec{E}$ is $E = \frac{U}{d}$, where U is the voltage across the plates and d is the separation between the plates ($6\,mm$). The upward electric force on the charge (negative charge) is $\vec{F}_E = q\vec{E}$.

$$\therefore F_g + F_d - qE = ma \Rightarrow \frac{4}{3}\pi r^3 \rho\, g + 6\pi\eta\, r v_2 - \frac{qU}{d} = 0$$

$$\Rightarrow q = \frac{d}{U}\left[\frac{4}{3}\pi r^3 \rho\, g + 6\pi\eta\, r v_2\right] \Rightarrow q = \frac{2\pi d\, r}{U}\left[\frac{2}{3} r^2 \rho\, g + 3\eta\, v_2\right]$$

Using the value of r from equation (1) in the above equation we get:

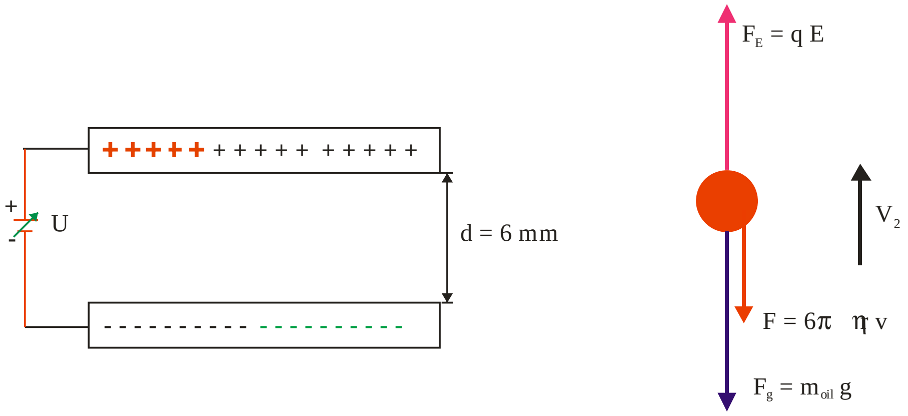
$$q = \frac{2\pi\, d}{U} \times \sqrt{\frac{9\eta\, v_1}{2\rho\, g}} \times \left[\frac{2}{3} \times \frac{9\eta\, v_1}{2\rho\, g} \times \rho\, g + 3\eta\, v_2\right] \Rightarrow q = \frac{2\pi\, d}{U} \times \sqrt{\frac{9\eta\, v_1}{2\rho\, g}} \times [3\eta\, v_1 + 3\eta\, v_2]$$

$$\Rightarrow q = \frac{2\pi\, d}{U} \times \frac{3\eta^{\frac{1}{2}} v_1^{\frac{1}{2}}}{\sqrt{2\rho\, g}} \times 3\eta\,(v_1 + v_2)$$

$$\Rightarrow q = \frac{18\pi\, d}{U} \times \frac{\eta^{\frac{3}{2}}\sqrt{v_1}}{\sqrt{2\rho\, g}}(v_1 + v_2)\, A\cdot s \qquad (2)$$

Substituting the values for $d = 6\ mm$, $\rho = 874\,\frac{kg}{m^3}$, $\eta = 1.86\times10^{-5}\,\frac{N}{m^2\, s}$, $g = 9.81\frac{m}{s^2}$, we get

$$q = 2\times10^{-10}(v_1 + v_2)\times\frac{\sqrt{v_1}}{U} A\cdot s \qquad (3)$$



(a) (b)

Figure 2. (a) Millikan oil drop chamber (plate capacitor), (b) The force on a droplet moving upward with the terminal velocity (v_2) under the influence of an electric field $(\vec{E})$.

- For a given oil drop, you will measure the fall time (t_f) in the absence of the electric field and the rise time (t_r) in the presence of the electric field over a fixed distance s. The fall and rise velocities can then be determined from $v_1 = \frac{s}{t_f}$ and $v_2 = \frac{s}{t_r}$ and the charge on the drop can be computed from equation 3.

Procedure

1 First you will get use to viewing the oil drops and observe their general behavior.

2 First look at the droplets with no voltage applied to the capacitor plates. You should see them mostly rising (although some large ones may be nearly stationary). Since they appear to be rising, they are actually falling under the influence of gravity.

- Now turn on the voltage to the capacitor plates (500 V). You will see some drops slow down and some will actually reverse direction (meaning they are actually rising). These are droplets with an excess negative charge that are attracted to the top plate of the capacitor. So they either slow the rate of fall of the drop or reverse it and start rising if the residual negative charge is large enough.
- On the other hand, you will see some droplets actually start to fall faster (or rise faster as you actually see it). These are positively charged drops that are attracted electrically to the bottom plate of the capacitor (that is the force on them is the same direction as the gravitational force).

3. The first thing to note is the calibration of the scale. The objective lens of the microscope has a **magnification of 2.00** and the eyepiece lens has a magnification of 10. So that means that the smallest division you see on the **micrometer scale corresponds to a length of .05 mm**. The distance between major scale divisions (which each have 10 minor divisions between them) is 0.5 mm. For convenience, all of your measurements should be done over the same vertical **fall distance 20 minor** scale divisions. That corresponds to a real vertical distance that the drop falls through **of 1.0 mm**.

4 For the quantitative part of the lab, you will just focus on negatively charged drops. Those are the ones that appear to be rising (actually falling) with 0 V applied, and then when you apply 500 V, they reverse direction and appear to be falling (actually rising). For each droplet you select, you want to measure the time it takes to fall through **20 minor scale** divisions and the time it takes to rise through 20 minor scale divisions. you will use those two numbers to determine the **radius** of each drop and the **charge** on it.

5 One partner should view the drop while the other runs the stopwatch. Each partner should get a chance to view drop.

Distance travel by the drop = s = mm,

Oil drop	Fall time t_f(s)	Rise time t_r(s)	$V_1 = s / 2 \times t_f$ (m / s)	$V_2 = s / 2 \times t_r$ (m / s)	Radius (r) of the drop (m)	Charge (q) on the drop (A.s)
1						
2						
3						
4						
5						

Results:

The charge of the droplets have certain values which are multiples of the elementary charge e, $q = ne$

As a mean value, the elementary charge is obtained as $e = \quad \times 10^{-19}\ A \cdot s$