Nalanda Open University.

B.SC Part-2

Course : Physics (Hons)

Paper : 4

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Topic- Modern Physics (Millikan Oil Drop Method)

Millikan Oil Drop Method for Determination of Charge of an Electron

Key points-

- Millikan's oil drop experiment measured the charge of an electron. Before this experiment, existence of subatomic particles was not universally accepted.
- Millikan's apparatus contained an electric field created between a parallel pair of metal plates, which were held apart by in-sulating material. Electrically charged oil droplets entered the electric field and were balanced between two plates by alter-ing the field.
- When the charged drops fell at a constant rate, the gravitational and electric forces on it were equal.

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.

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.

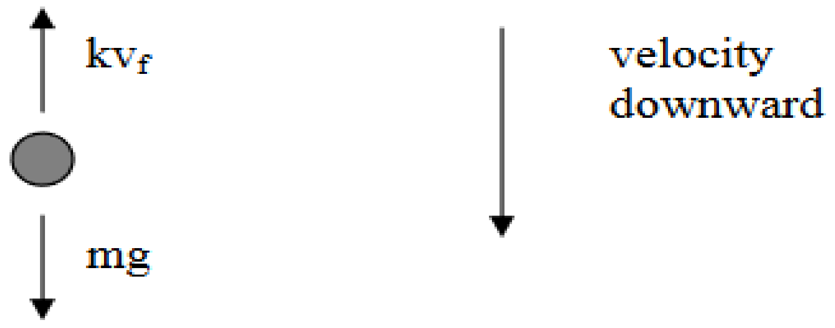


Figure 1

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:

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

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

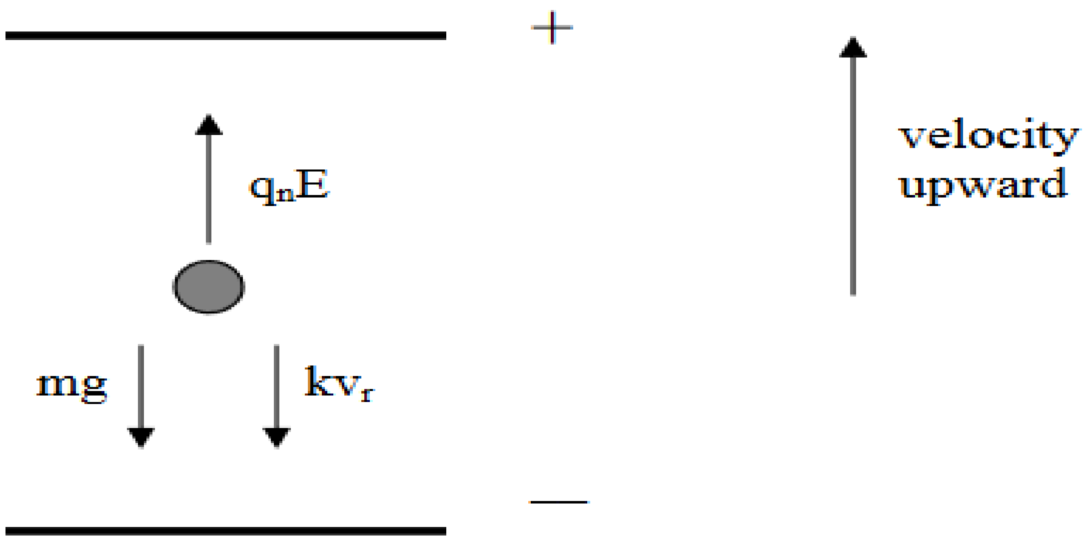


Figure 2

Applying Newton's 2nd Law again we have:

$$q_nE - mg - kv_r = 0 \qquad \text{(E-field on)} \qquad (2)$$

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:

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

The electric field in the region of the oil drop is produced by to 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:

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

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

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

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:

$$F = 6\pi\eta a v_f \qquad (5)$$

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:

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

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:

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

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:

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

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).

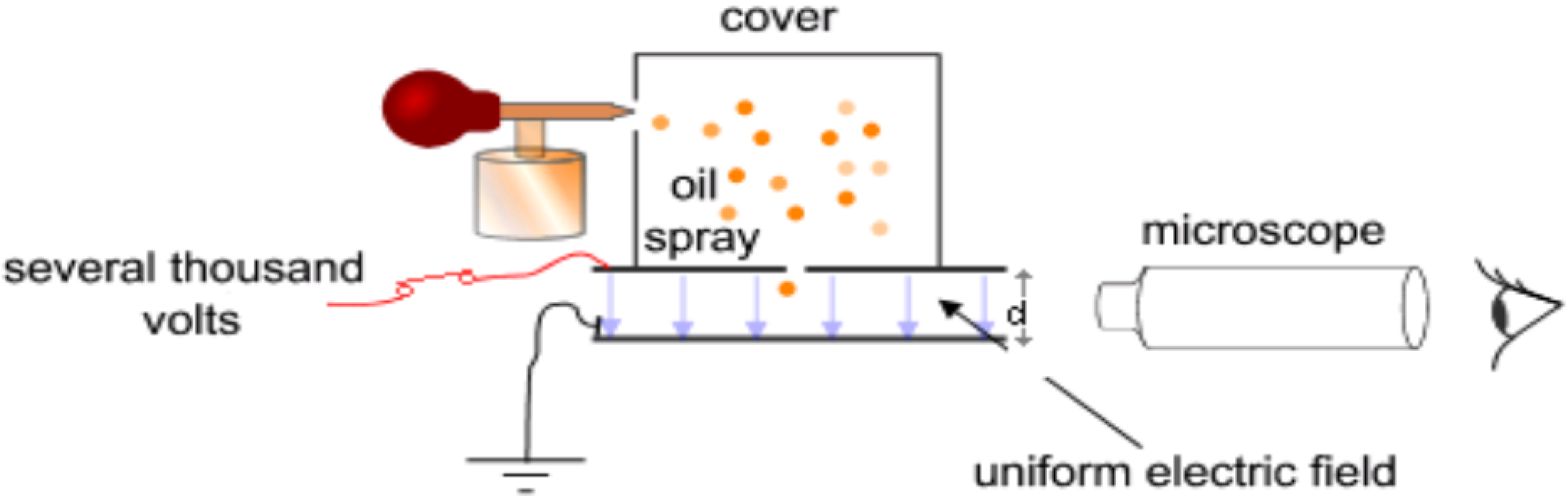
e_n = The charge, in coulombs, carried by the droplet
d = Separation of the plates in the condenser in meters
σ = Density of oil in kg/m^3 ($886\ kg/m^3$)
ρ = Density of air in kg/m^3 (See Appendix C)
g = Acceleration of gravity in m/s^2
η = Viscosity of air in poise (Ns/m^2) (See Appendix A)
b = Constant,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

How did this process works?

The figure below shows a simplified scheme of Millikan's oil drop experiment. The apparatus incorporated a pair of metal plates and a specific type of oil. Millikan and Fletcher discovered it was best to use an oil with an extremely low vapor pressure, such as one designed for use in a vacuum apparatus. Ordinary oil would evaporate under the heat of the light source, causing the mass of the oil drop to change over the course of the experiment.

By applying a potential difference across a parallel pair of horizontal metal plates, a uniform electric field was created in the space between them. A ring of insulating material was used to hold the plates apart. Four holes were cut into the ring—three for illumination by a bright light and another to allow viewing through a microscope. A fine mist of oil droplets was sprayed into a chamber above the plates. The oil drops became electrically charged through friction with the nozzle as they were sprayed. Alternatively, charge could be induced by including an ionizing radiation source (such as an X-ray tube).



Simplified scheme of Millikan's oil-drop experiment This apparatus has a parallel pair of horizontal metal plates. A uniform electric field is created between them. The ring has three holes for illumination and one for viewing through a microscope. A specific type of oil is sprayed into the chamber, where drops become electrically charged. The droplets enter the space between the plates and can be controlled by changing the voltage across the plates.

The droplets entered the space between the plates and, because they were charged, they could be controlled by changing the voltage across the plates. Initially, the oil drops were allowed to fall between the plates with the electric field turned off. They quickly reached terminal velocity due to friction with the air in the chamber. The field was turned on and, if it was large enough, some of the drops (the charged ones) would start to rise. This is because the upwards electric force, F_E, is greater for them than the downwards gravitational force, *g*. (A charged rubber rod can pick up bits of paper in the same way.) A likely looking drop was selected and kept in the middle of the field of view by alternately switching off the voltage until all the other drops fell. The experiment was continued with this single drop.