Millikan's Oil Drop Experiment

The experimental arrangement for the Millikan's oil drop experiment is shown in Fig.

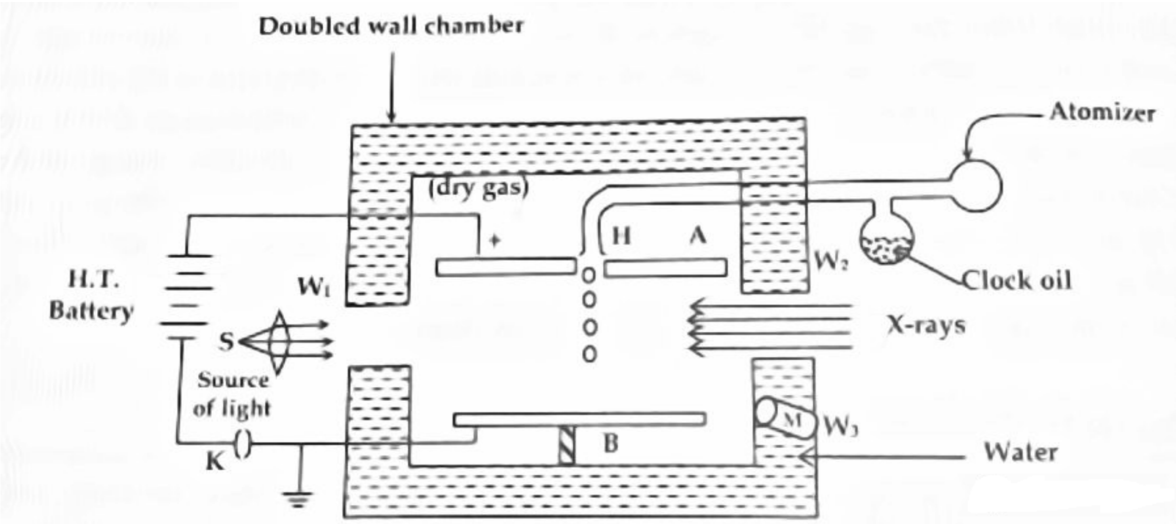


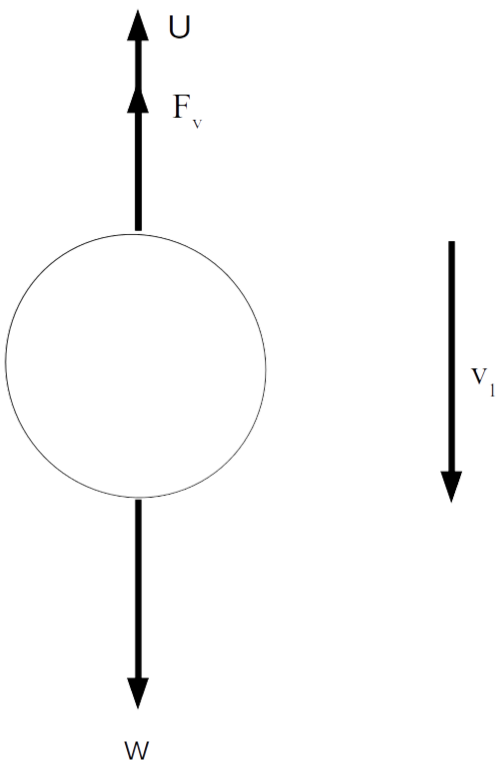
Fig: Experimental arrangement for Millikan's oil drop experiment

It consists of two parallel metal plates A and B with upper plate A maintained at high potential by connecting it to a high tension battery while the lower plate B is earthed so that the region between the plates is a region of uniform electric field. The upper plate has a hole H at is centre through which small charged oil drops are sprayed in the region between plates. The oil drops are charged due to friction with air when squeezed through the atomizer. The whole arrangement is kept inside double walled jacket in which cold water keeps on circulating so that the internal temperature remains constant. This jacket also helps to prevent the zigzag motion of oil drop which would otherwise arise due to the convection current of air set up by the external conditions.

The jacket is also provided with three openings W_1, W_2, and W_3 in the form of windows. Window W_1 has an electric bulb to illuminate the region between the plates. Window W_2 has a source of X-ray that may be used to charge the oil drop, if the friction with the air is not sufficient enough to charge it. The window W_3 has a travelling microscope which would help to calculate the terminal velocity acquired by oil drop by measuring the distance travelled by it.

This experiment is carried out in two steps:

i) Motion of oil drop under the effect of gravity alone
First of all, the charged oil drop is allowed to fall under the action of gravity alone by switching off the electric field. As the oil drop falls, its velocity keeps on increasing until a stage reaches when the net force acting on the oil drop becomes zero i.e. the upward forces; upthrust and viscous force equals the downward force; gravity. Now, the oil drop falls with the constant velocity called v_1 called terminal velocity.



Let, m = mass of oil drop

r = radius of oil drop

ρ = density of the oil

σ = density of air

For, Net force = 0

Upthrust + viscous force = weight

or, Volume of air displaced x density of air x acceleration due to gravity + $6\pi\eta r v_1$ = mass of oil drop x acceleration due to gravity

or, Volume of oil drop x density of air x acceleration due to gravity + $6\pi\eta r v_1$ = mass of oil drop x acceleration due to gravity

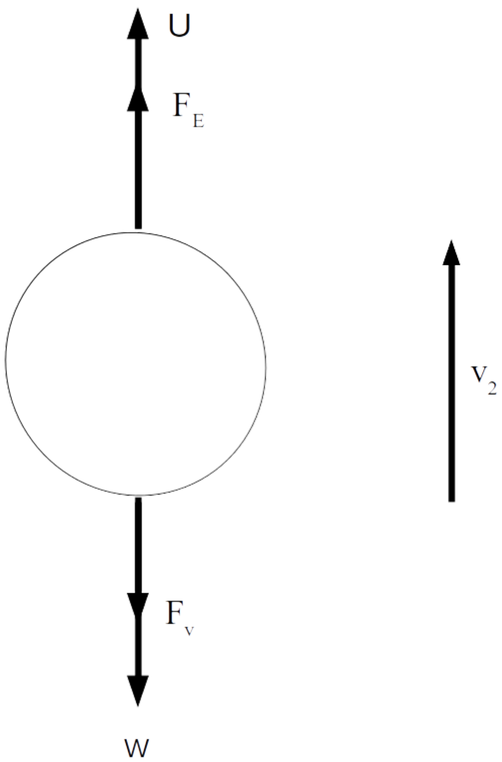
or, $\frac{4}{3}\pi r^3\sigma g$ + $6\pi\eta r v_1$ = $\frac{4}{3}\pi r^3\rho g$

or, $6\pi\eta r v_1$ = $\frac{4}{3}\pi r^3(\rho-\sigma)g$ .... (i)

$r = \sqrt{\frac{9\eta v_1}{2(\rho-\sigma)g}}$ .... (ii)

ii) Motion of oil drop under the combined effect of electric field and gravity

Now, the experiment is conducted by applying a strong electric field between the plates so that the electric force due to the electric field on the identical oil drop which is negatively charged acts on the vertically upward direction. Again, the velocity of oil drop keeps on increasing in upward direction until a stage reaches when the net force acting on the oil drop becomes zero i.e. the upward forces; upthrust and electric force equals the downward force; gravity and viscous force. Now, the oil drop moves with the constant velocity called v_2 called terminal velocity in upward direction. Let, Q be the total charge on the oil drop and E be the electric field strength.



For, Net force = 0

Upthrust + Electric force = weight + viscous force

or, Volume of air displaced x density of air x acceleration due to gravity + QE = mass of oil drop x acceleration due to gravity + $6\pi\eta r v_2$

or, Volume of oil drop x density of air x acceleration due to gravity + QE = mass of oil drop x acceleration due to gravity + $6\pi\eta r v_2$

or, QE = mass of oil drop x acceleration due to gravity - Volume of oil drop x density of air x acceleration due to gravity + $6\pi\eta r v_2$

or, QE = $\frac{4}{3}\pi r^3 \rho g$ - $\frac{4}{3}\pi r^3 \sigma g$ + $6\pi\eta r v_2$

or, QE = $\frac{4}{3}\pi r^3(\rho - \sigma)g + 6\pi\eta r v_2$

or, QE = $6\pi\eta r v_1$ + $6\pi\eta r v_2$ [From (i)] or, $Q = \frac{6\pi\eta r(v_1+v_2)}{E}$ ....(iii)

Substituting the value of 'r' from (ii) into (iii), we have

$$Q = \frac{6\pi\eta}{E}\sqrt{\frac{9\eta v_1}{2(\rho-\sigma)g}}(v_1 + v_2) \text{ ....(iv)}$$

This is the required expression for the total charge carried by an oil drop. Knowing all the quantities on the right hand side of eqn(iv); through the series of experiments conducted for the oil drop of different sizes, Millikan determined that the value of charge Q carried by an oil drop is an integral multiple of $1.6 \times 10^{-19}C$ which is the charge carried by an electron. So, the total charge Q on the oil drop could be expressed as,

$Q = \pm ne$ where, n = 1,2,3,..... and e = $1.6 \times 10^{-19}C$

Thus, Millikan's experiment proved the quantization of charge i.e. the charge on any charged object exists as an integral multiple of small minimum units called quantum of charge which is equivalent to $1.6 \times 10^{-19}C$, the charge of an electron. This is known as the quantization of charge.

Roshan Shrestha

roshanpra@gmail.com