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B.Sc - Part - II (Hons)

Modern Physics

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Measurement of charge on an electron by Millikan's method.

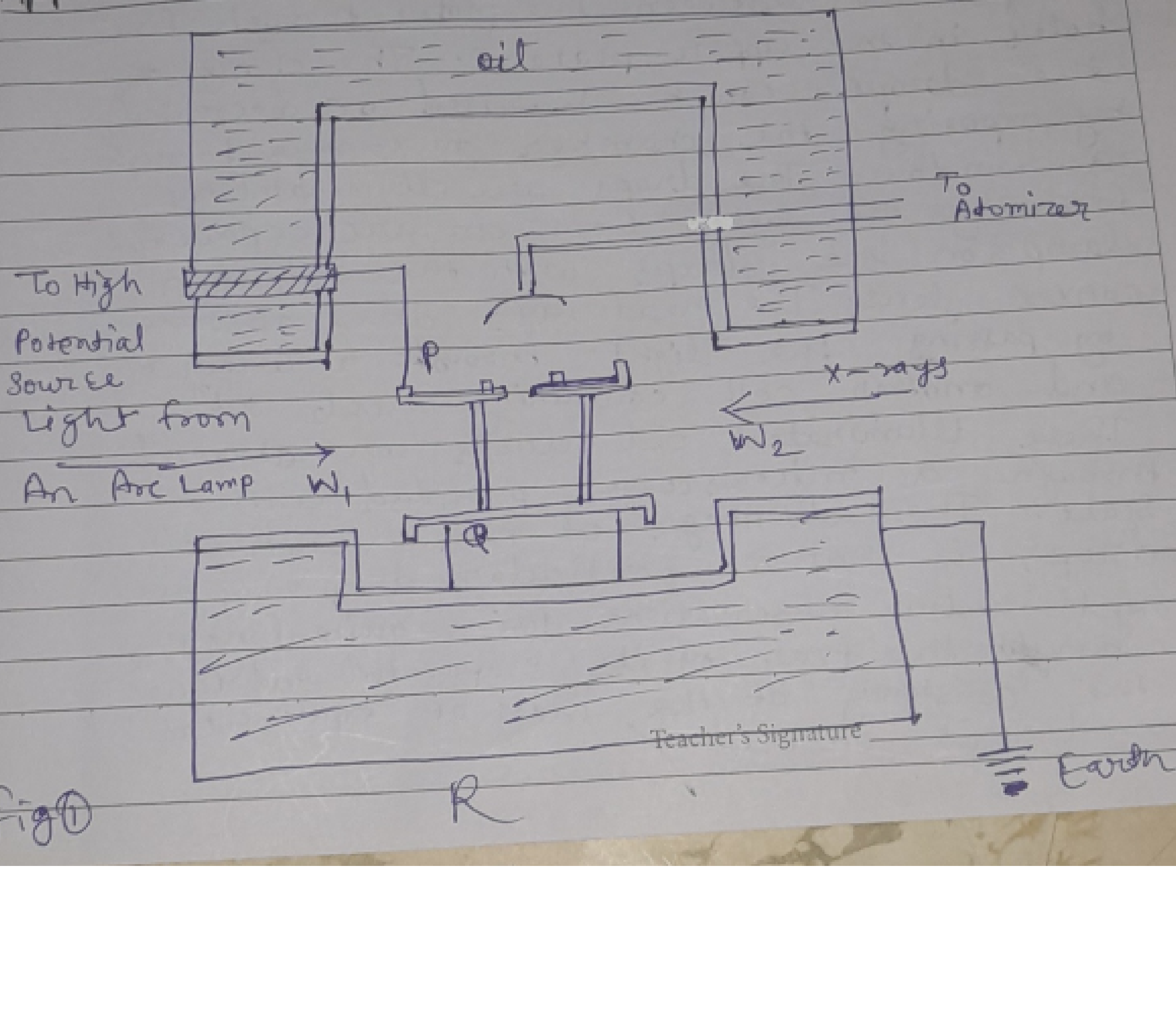
Electron and Isotopes chapter

Introduction :- Electron is an important constituent of matter. It was discovered by J.J. Thomson. Its charge is 1.6×10^{-29} coulomb and its mas is 9.1×10^{31} kg. Thomson gave a method to find the specific charge (e/m)

Measurement of charge on an electron by Millikan's Method

In the beginning of 20^{th} century Robert A. Millikan performed a series of experiments to determine the charge on an oil drop. One of the experiments performed by him in 1914 gave most accurate results.

Apparatus and Working :- It consists of two flat



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fig①

metal plates P and Q made optically plane and parallel separated by three optically plane and parallel glass (or ebonite) plates of about 1.5cm in thickness. The upper plate has some fine holes through which non-volatile oil drops can be introduced into the space between the plates. These plates are enclosed in an earthed metal champer R surrounded by a constant temperature oil bath having two windows W_1 and W_2. The plate Q is earthed and a high potential difference from (3000 to 10000 volts) is applied between the two plates by a high tension battery.

A fine spray of oil drops is produced by an atomized in the chamber above the two plates. The drops become charged during spraying due to friction. Some of the oil drops enter between the plates through fine holes in the upper plate P. The charge on the drops can be increased or decreased by exposing the chamber to X-rays through a window. The drops are illuminated by focussing the light from an arc or powerful lamp on the drops with the help of a convex lens. The heat rays are absorbed by passing the light through a water cell and another cell containing $CuCl_2$ sol^n. These illuminated oil drops are observed through a microscope provided with a scale. The advantage of non-volatile oil drops is that a particular drop may be kept under observations for a quite long time without the fear of its evaporated and thus the constancy of the mass of experimental drop is ensured.

of view. Now, one of these drops [illegible] observations. Firstly the electric field is so adjusted that this experimental drop moves with constant upward velocity known as terminal velocity v_2 under the combined effect of gravitational, electrical and viscous forces. This velocity is determined by noting its time of travel for a known distance. Then the electric field is switched off and both the plates P and Q are earthed. Now the same drop will fall with constant velocity v_1 under the effect of gravitational and viscous forces. This velocity is again determined by noting its time of travel for a known distance.

Theory :- <u>Motion under gravitational field alone</u> :- when the electric field is switched off, the experimental drop falls freely under gravity, which is opposed by the viscosity of air. When the downward gravitational force is balanced by upward viscous force, the drop acquires a steady velocity v_1.

The downward gravitational force is mg and the upward viscous force according to Stoke's law of $6\pi\eta v_1$, so that

$$mg = 6\pi\eta a v_1 \quad \text{—— (1)}$$

when η is the coefficient viscosity for air and a is the radius of the drop.

<u>Motion under simultaneously electric and gravitational fields</u> :-

When the experimental drop moves slowly upward with constant velocity v_2 under the combined effect of gravitational, electrical and viscous forces: If G is the intensity of electric field, q is the charge, then electric force qE (upward) so that the force acting on the drop is $qE - mg$. This force tends to increase the velocity of the drop in the upward direction, which is opposed by the viscosity of the air. When the upward force is balanced by the downward viscous force, the drop acquires the steady velocity v_2. According to Stoke's law, the viscous force on the drop will be $6\pi\eta a v_2$. Therefore,

$$qE - mg = 6\pi\eta a v_2 \quad \text{—— (2)}$$

Adding equations (1) and (2), we get

$$qE = 6\pi\eta a(v_1 + v_2) \quad \text{--- (3)}$$

Dividing eqn (3) by (1)

$$\frac{qE}{mg} = \frac{v_1 + v_2}{v_1} \quad \text{--- (4)}$$

$$q = \frac{v_1 + v_2}{v_1} \cdot \frac{mg}{E} \quad \text{--- (5)}$$

If ρ and σ are the densities of oil and air respectively, we have effective weight of oil drop

$$mg = \frac{4}{3}\pi a^3 \rho g - \frac{4}{3}\pi a^3 \sigma g = \frac{4}{3}\pi(\rho - \sigma) a^3 g \quad \text{--- (6)}$$

Substituting value of a from eqn (1) in above eqn, we have

$$mg = \frac{4}{3}\pi(\rho - \sigma)\left(\frac{mg}{6\pi\eta v_1}\right)^3 \cdot g$$

$$mg = \frac{(6\pi\eta v_1)^{3/2}}{\left[\frac{4}{3}\pi(\rho - \sigma)g\right]^{1/2}} \quad \text{--- (7)}$$

Substituting this value of mg in eqn (5),

$$q = \frac{v_1 + v_2}{v_1}\left(\frac{1}{E}\right)\frac{(6\pi\eta v_1)^{3/2}}{\left[\frac{4}{3}\pi(\rho - \sigma)\right]^{1/2}} \quad \text{--- (8)}$$

Knowing the value of each quantity of R.H.S. the charge q on a drop can be determined. Milikan performed the experiment on a large number of drops and found that the charge was always an integral multiple of $(e =) 1.6 \times 10^{-19}$ coulomb.

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i.e., $\frac{q}{e} = n$ (an integer). The common factor e is the electronic charge.

Thus Millikan's oil drop experiment confirms the quantum nature of charge.

By the use of Millikan's oil drop experiment the following quantities may also be determined.

1. Mass of electron :— The mass m of electron is found by the experimental values of e and $\left(\frac{e}{m}\right)$ of electron

$$m = \frac{e}{e/m} = \frac{1.602 \times 10^{-19} \text{ coul}}{1.75 \times 10^{11} \text{ coul/kg}}$$

$$= 9.109 \times 10^{-31} \text{ kg}$$

2. Radius of Electron : If the electron is assumed to have spherical shape of radius and uniform charge distribution. Then the radius of electron may be found using the expression.

Rest energy = electrostatic self energy of electron

$$mc^2 = \frac{1}{4\pi\epsilon_0} \cdot \frac{3e^2}{5a}$$

$$a = \frac{1}{4\pi\epsilon_0} \cdot \frac{3}{5} \frac{e^2}{mc^2}$$

$$= 9 \times 10^9 \times \frac{3}{5} \times \frac{(1.602 \times 10^{-19})^2}{9.109 \times 10^{-31} \times (3 \times 10^8)^2}$$

$$= 1.998 \times 10^{-15} \text{ m}$$

Avogadro Number (N_A): Avogadro number is the number of atoms in 1 kg-atom of substance. From electrolysis it is known that the charge of N_A electrons is 9.65×10^7 coulombs.

$$N_A e = 9.65 \times 10^7$$

$$\therefore N_A = \frac{9.65 \times 10^7}{e} = \frac{9.61 \times 10^7}{1.602 \times 10^{-19}} = 6.023 \times 10^{26} \ (kg\,mol^{-1})$$

4. Mass of hydrogen Atom

The mass of hydrogen atom $m_H = \frac{\text{Atomic weight of hydrogen}}{\text{Avogadro number}}$

$$= \frac{1.008}{6.023 \times 10^{26}} = 1.67 \times 10^{-27}\ kg.$$