Atomic Structure part-2

Millikan's Oil Drop Experiment

Introduction

Robert A. Millikan's oil drop experiment, conducted in 1909, was designed to measure the elementary electric charge (the charge of the electron). Millikan's work provided the first accurate value for the charge of the electron and confirmed the quantized nature of electric charge.

Experimental Setup

Millikan used a transparent chamber with a uniform electric field created between two horizontal metal plates. The chamber contained a fine mist of oil droplets, produced by an atomizer. The droplets fell through a small hole in the upper plate into the space between the plates. Millikan observed the droplets through a microscope and used a light source to illuminate them.

Procedure

1. **Observation Without Electric Field:**
   - Millikan first observed the motion of the oil droplets falling under gravity. By measuring the terminal velocity of the droplets, he could determine their radii and masses using Stokes' law.
2. **Application of Electric Field:**
   - When an electric field was applied, the oil droplets experienced an electric force in addition to the gravitational force. By adjusting the strength of the electric field, Millikan could balance the electric force with the gravitational force, causing the droplets to be suspended in mid-air or move upward.

Forces Acting on the Droplet

In the absence of the electric field, the forces acting on a droplet in equilibrium are the gravitational force and the viscous drag force. The gravitational force (F_g) is given by:

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

where:

- m is the mass of the droplet,
- g is the acceleration due to gravity,
- r is the radius of the droplet,
- ρ is the density of the oil.

The viscous drag force (F_d) is given by Stokes' law:

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

where:

- η is the viscosity of air,
- v is the terminal velocity of the droplet.

At terminal velocity, the gravitational force equals the drag force:

$$mg = 6\pi\eta r v$$

Determining the Radius and Mass of the Droplet

From the terminal velocity (v):

$$r = \sqrt{\frac{9\eta v}{2\rho g}}$$

The mass of the droplet is:

$$m = \frac{4}{3}\pi r^3 \rho$$

With Electric Field Applied

When an electric field (E) is applied, the electric force (F_e) on a charged droplet is:

$$F_e = qE$$

where q is the charge on the droplet.
At equilibrium, the electric force balances the gravitational force:

$$qE = mg$$

Combining the expressions:

$$qE = 6\pi\eta r v$$

or

$$q = \frac{6\pi\eta r v}{E}$$

Since v and E can be measured and r can be determined from the initial fall without the electric field, q can be calculated.

Determining the Elementary Charge

Millikan observed that the charges on different droplets were always multiples of a smallest value, which he identified as the elementary charge (e). By averaging the measured charges of many droplets, he determined the value of e:

$$e \approx 1.602 \times 10^{-19}\,\mathrm{C}$$