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ATOMS

- **Plum pudding model**

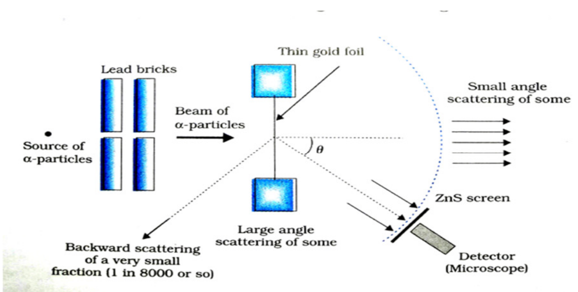
  It was the first atom model suggested by J.J. Thomson. According to it, the positive charge of the atom is uniformly distributed throughout the volume of the atom. Electrons are embedded in it like seeds in watermelon.

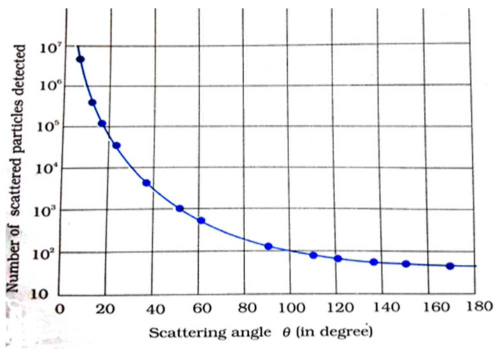
- **Nuclear atom model (planetary model)**

  This model was suggested by Rutherford. According to it, the positive charge and hence the entire mass of the atom is concentrated at the centre of the atom called nucleus. The electrons are revolving round it like planets revolving round the sun.

- **Alpha particle scattering experiment (Ginger-Marsden experiment)**

  The alpha particles emitted by ${Bi_{83}}^{214}$ of energy about 5.5MeV are allowed to fall on a gold foil of thickness about $2.1\times 10^{-7}m$. The narrow beam of ∝ particles is obtained by passing them through the slit between lead bricks .





❖ Observations:

Many of the alpha particles passed through the foil. They do not suffer any collision. About 0.14% of the incident ∝ particles are scattered at an angle greater than1^{o}. About one in 8000 deflects more than 90^{o}.

❖ Conclusions:

Many of the ∝ particles passed through the foil means atom contains so much empty space. Alpha particles which are very close to the nuclease are scattered at great angles. Alpha particles which are at a distance from the nucleus are scattered at small angles. As the foil is thin, the alpha particles will not suffer more than one scattering during passage. The scattered ∝ particles are detected using a detector which is movable over a circular scale.

- **Distance of closest approach**

If an alpha particle moves directly towards the centre of nucleus, the coulomb's repulsion on it by the nucleus increases. Kinetic energy of the electron gets progressively converted to electrical energy. At a particular distance from the nucleus, the alpha particle stops for a moment and then it retraces its path (scattered through180^0). This distance is called the distance of closest approach (r_0). At this distance, the entire kinetic energy of ∝ particle gets converted to electrostatic potential energy.

Charge of ∝ particle (q_1) = +2e

Charge of nucleus (q_2) = +Ze where Z is the atomic number.

Initial K.E of ∝ particle (KE) = $\frac{1}{2}mv^2$

Electrostatic potential energy (PE) = $\frac{K\, q_1\, q_1}{r_0}$

At distance of closest approach KE = PE

$\frac{1}{2}\, mv^2 = \frac{K\, q_1\, q_1}{r_0}$

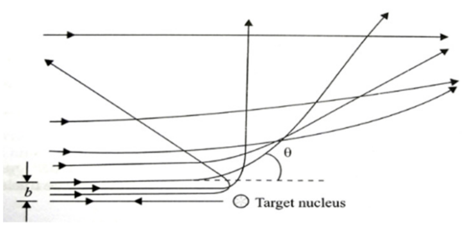
or

$r_0 = \frac{2K\, q_1\, q_1}{mv^2}$

$r_0 = \frac{2K\; 2eZe}{mv^2}$

ie, $r_0 = \frac{4\, k\, Z\, e^2}{mv^2}$

- **Impact parameter**



It is the perpendicular distance between the centre of nucleus and direction of initial velocity of alpha particles. If impact parameter is small, there is large scattering. If impact parameter is large, deflection is small.

Impact parameter (b) = $\frac{1}{4\pi\varepsilon_0}\frac{Z\,e^2 \cot\theta/2}{K}$ where θ is the scattering angle and K is the kinetic energy of ∝ particle.

- **Radius and energy of electron in the orbit of hydrogen atom**

For the electron in the orbit, the centripetal force is provided by electrostatic force between the nucleus and the electron.

$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$ or $mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$

r = $\frac{1}{4\pi\varepsilon_0}\frac{e^2}{mv^2}$

Kinetic of energy of electron = $\frac{1}{2}mv^2 = \frac{1}{2}\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} = \frac{1}{8\pi\varepsilon_0}\frac{e^2}{r}$

Potential energy of electron = $\frac{1}{4\pi\varepsilon_0} \times \frac{e\times -e}{r} = -\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$

Total energy = KE + PE

$$= \frac{e^2}{8\pi\varepsilon_0 r} + \frac{-e^2}{4\,\pi\varepsilon_0 r} = \frac{e^2}{8\pi\varepsilon_0 r} + \frac{-2e^2}{8\pi\varepsilon_0 r} = \frac{-\,e^2}{8\pi\varepsilon_0 r}$$

Total energy is negative . It shows that the electron is bound to the nucleus.

- **Emission spectrum and absorption spectrum**

Each element has a characteristic spectrum of radiation. During the electric discharge through an atomic gas or atomic vapour at low pressure, some radiations are emitted. Its spectrum consists of some specific wave lengths only. Such a spectrum is called emission spectrum (we get bright lines on dark ground).

When white light is passed through a gas and if we analyze the transmitted light through a spectrometer we get dark lines. This type of a spectrum is called absorption spectrum.

- **Different spectral series**

The different spectral series in hydrogen spectra are,

(a) Lyman series (UV region)

Empirical formula $\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$ where R is Rydberg's constant. R = 1.097× $10^7 m^{-1}$ where n = 2,3,4 ….

(b) Balmer series(visible region)

Empirical formula $\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$ where n= 3,4,5……..

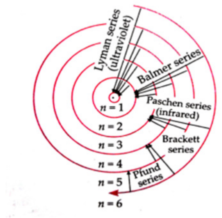
(c) Paschen series (IR region)

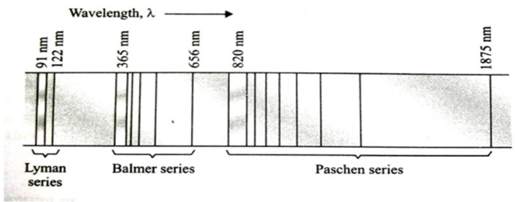
Empirical formula $\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right)$ where n= 4,5,6…………

(d) Brackett series (IR region)

Empirical formula $\frac{1}{\lambda}$ = R $\left(\frac{1}{4^2} - \frac{1}{n^2}\right)$ where n= 5,6,7........

(e) Pfund series (far IR region) Empirical formula $\frac{1}{\lambda}$ = R $\left(\frac{1}{5^2} - \frac{1}{n^2}\right)$ where n = 6,7,8.......

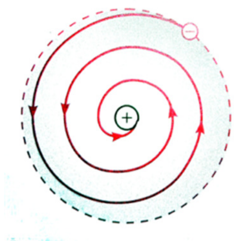




- **Drawback of classical electromagnetic theory in explaining the electromagnetic wave emission by revolving electron**

According to it, the electron in an orbit is constantly accelerated. So it emits electromagnetic radiations. Energy of the electron decreases. It moves in a spiral orbit and finally falls into the nucleus. The atom will not be stable.

According to this theory, frequency of electromagnetic waves emitted by revolving electron is equal to frequency of revolution. When it spirals inwards, angular frequency changes and frequency of radiation emitted also changes. So they emit a continuous spectrum. But actually we get a line spectrum.



- **Bohr's postulates**

(a) An electron in an atom revolves in stable orbit without emitting electromagnetic radiations.

(b) Angular momentum of an electron in an orbit is an integral multiple of $\frac{h}{2\pi}$ where h is Planck's constant.

(c) During the transition of an electron from one orbit to another lower energy orbit, a photon having energy equal to the difference in energy between the orbits is emitted.

- **Velocity and total energy of electron in hydrogen atom using Bohr's theory**

According to Bohr's theory, the angular momentum of an electron in its orbit is

$$L = \frac{nh}{2\pi}$$

But L = mvr

For the nth orbit, $mv_n r_n = \frac{nh}{2\pi}$ -----------(1)

But we have $r_n = \frac{e^2}{4\pi\varepsilon_0 \, mv_n^2}$ OR $v_n^2 = \frac{e^2}{4\pi\varepsilon_0 \, mr_n}$

Or $v_n = \frac{e}{\sqrt{4\pi\varepsilon_0\ mr_n}}$--------------(2)

Putting in (1)

$$\frac{m \times e}{\sqrt{4\pi\varepsilon_0\ mr_n}} \times r_n = \frac{nh}{2\pi}$$

Squaring $\frac{m^2e^2r_n^2}{4\pi\varepsilon_0\ mr_n} = \frac{n^2h^2}{4\pi^2}$

$$\frac{m\,e^2r_n}{\varepsilon_0} = \frac{n^2h^2}{\pi}$$

OR $me^2r_n\,\pi = n^2h^2\varepsilon_0$

$$r_n = \frac{n^2h^2\,\varepsilon_0}{me^2\,\pi} \text{ -------------(3)}$$

When n= 1 r_1 or $a_0 = \frac{h^2\,\varepsilon_0}{me^2\,\pi}$

This is the expression for Bohr's radius.

Putting (3) in (2) $v_n = \frac{e}{\sqrt{4\pi\varepsilon_0\, m\frac{n^2h^2\,\varepsilon_0}{me^2\,\pi}}}$

$$v_n = \frac{e}{2\varepsilon_0 n\frac{h}{e}}$$

or $v_n = \frac{e^2}{2\varepsilon_0\ nh}$

Total energy of electron $= \frac{-e^2}{8\pi\varepsilon_0\,r_n}$

$$= \frac{-e^2}{8\pi\varepsilon_0 \times \frac{n^2h^2\,\varepsilon_0}{me^2\,\pi}}$$

$$= \frac{-me^4}{8\,\varepsilon_0^2\ n^2h^2}$$

$$= \frac{-13.6}{n^2}\ eV$$

- The energy of electron in the first orbit (ground state) of hydrogen is -13.6eV.

- **For hydrogen atom**

First excited state energy = $\frac{-13.6}{n^2}\ eV$ = $\frac{-13.6}{2^2}\ eV$ = −3.40 eV

Second excited state energy= $\frac{-13.6}{n^2}\ eV$ = $\frac{-13.6}{3^2}\ eV$ = — 1.51 eV

- **Frequency of photon emitted during a transition in hydrogen atom**

Consider an electron in an excited energy level E_i returns to a lower energy level E_f .

Radiation of energy an electron in an energy $h\vartheta_{if}$ is emitted.

$$h\vartheta_{if} = E_i - E_f$$

We have $E_n = \frac{-me^4}{8\,\varepsilon_0^2\ n^2h^2}$

$$h\vartheta_{if} = \frac{-me^4}{8\,\varepsilon_0^2\ {n_i}^2h^2} - \frac{-me^4}{8\,\varepsilon_0^2\ {n_f}^2h^2}$$

$$= \frac{-me^4}{8\,\varepsilon_0^2\ {n_i}^2h^2} + \frac{me^4}{8\,\varepsilon_0^2\ {n_f}^2h^2}$$

$$h\vartheta_{if} = \frac{me^4}{8\,\varepsilon_0^2\ h^2}\left[\frac{1}{n_f^2} - \frac{1}{{n_i}^2}\right]$$

This formula is called Rydberg's formula.

$$\vartheta_{if} = \frac{me^4}{8\,\varepsilon_0^2\ h^3}\left[\frac{1}{n_f^2} - \frac{1}{{n_i}^2}\right]$$

This is the frequency of photon emitted during the transition.

$$\vartheta_{if} = \frac{c}{\lambda}$$

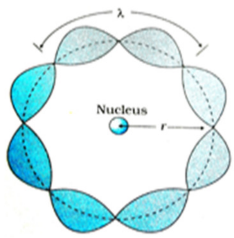
$$\frac{c}{\lambda} = \frac{me^4}{8\,\varepsilon_0^2\ h^3}\left[\frac{1}{n_f^2} - \frac{1}{{n_i}^2}\right]$$

OR $\frac{1}{\lambda} = \frac{me^4}{8\,\varepsilon_0^2\ h^3c}\left[\frac{1}{n_f^2} - \frac{1}{{n_i}^2}\right]$

But $\frac{1}{\lambda} = R\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$

$\therefore$ $R = \frac{me^4}{8\,\varepsilon_0^2\,h^3c}$ where R is Rydberg's constant.

- **<u>De-Broglie's explanation of Bohr's Second Postulate</u>**



Electron in an orbit can be associated with a wave. It produces standing waves under resonance conditions. In each orbit, integral multiple of λ are produced.

$2\pi r = n\lambda$

But $\lambda = \frac{h}{mv}$

$\therefore$ $2\pi r = n\frac{h}{mv}$

OR $mvr = \frac{nh}{2\pi}$

mvr = L (angular momentum)

$\therefore$ $L = \frac{nh}{2\pi}$

- **Limitations of Bohr's postulates**

It is applicable to hydrogenic atoms only.

It could not explain the relative intensities of spectral lines.

- **Excitation**

It is the process by which electrons absorb energy and move to higher energy levels.

- The amount of energy absorbed by an electron to move from ground state to higher energy state is called **excitation energy.**