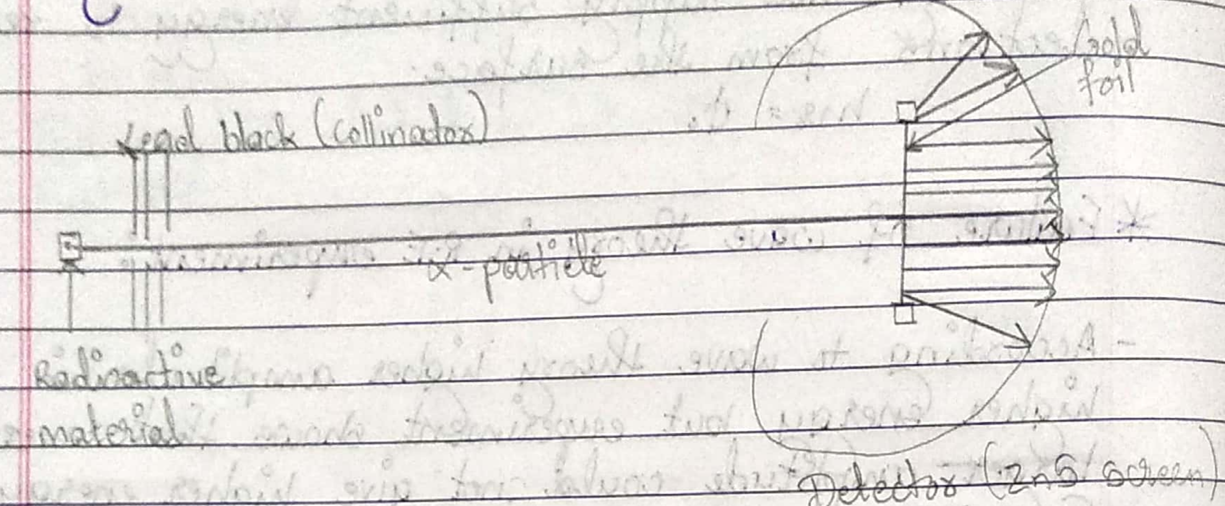
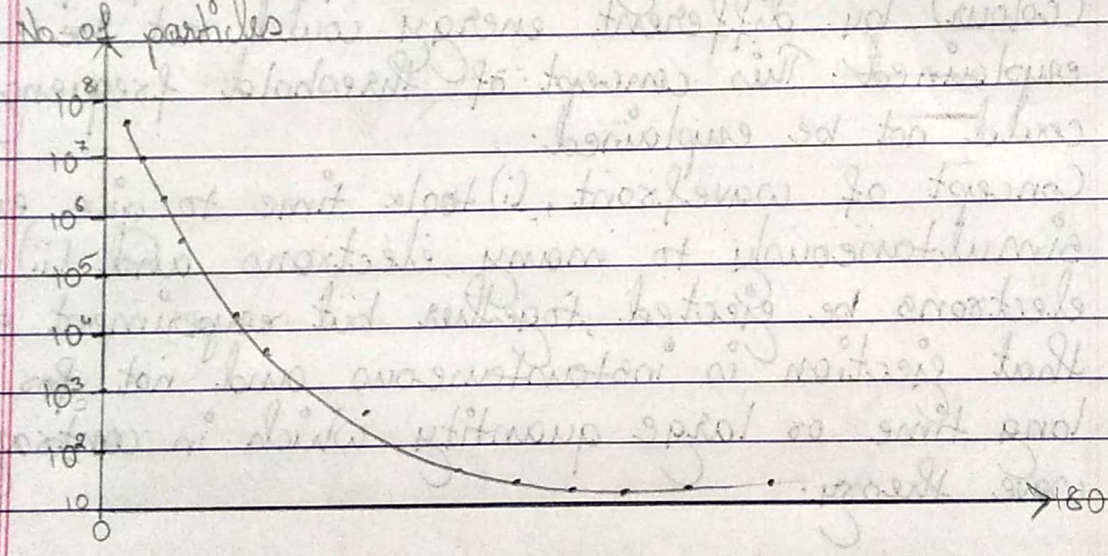
Chp-12: Atoms

* Geiger and Marsden experiment:





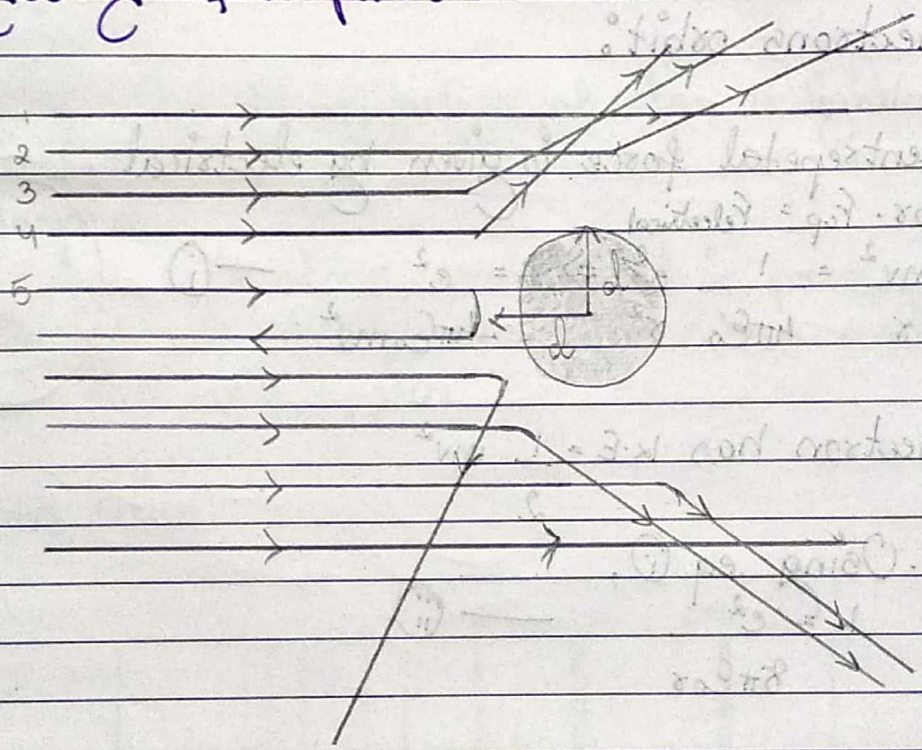
- Most of them passed through straight without deviation (No force acting, no collision) within 1°.
- A very small part reflected back (1 out of 8000).
- Conclusions:

① Space in the atom is mostly empty. (only 0.14% scatter more than 1°) only 1 out of 8000 reflected for more than 180°.

② Experiment suggested that all positively charged particles are together at one location at centre. It was called "nucleus". So nucleus has all the positive charge and mass. Therefore it has capacity to reflect α particles.

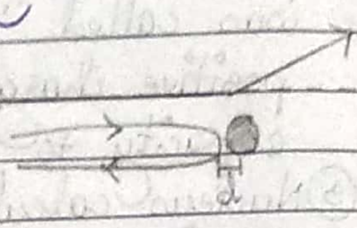
③ Nucleus calculated to be about 10^{-14} nm. According to kinetic theory of one atom is 10^{-10} m. It shows nucleus has empty space 10,000 times.

* Trajectory of α particles:



- Impact parameter is perpendicular distance between direction of given α particle and centre of nucleus.
- Distance of closest approach 'd' for an α particle in the line to centre of nucleus, is the distance between centre of nucleus and particle stops and returns back. This distance gives approximate size of nucleus.

* Force between α particle and gold nucleus:



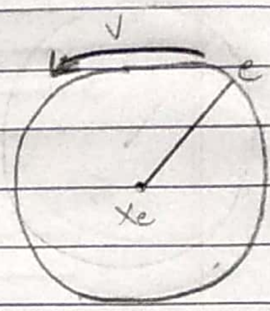
$F = \frac{1}{4\pi\varepsilon_0} \frac{2e \cdot Ze}{r^2}$ (Ze for gold 79)

F is repulsive.

If kinetic energy of α particle is 'k';

$k = \frac{1}{4\pi\varepsilon_0} \frac{2eZe}{d} \Rightarrow d = \frac{1}{4\pi\varepsilon_0} \frac{2Z \cdot e^2}{k}$

* Electrons orbit:



Centrepetal force is given by electrical for. $F_{cp} = F_{electrical}$

$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0} \frac{e^2}{r^2} \Rightarrow r = \frac{e^2}{4\pi\varepsilon_0 mv^2}$ — (i)

Electron has $k.E = \frac{1}{2} mv^2$

∴ Using eq (i),

$k = \frac{e^2}{8\pi\varepsilon_0 r}$ — (ii)

Electron has $P.E\ (U) = -\frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r} = -\frac{1}{4\pi\varepsilon_0} \frac{e^2}{r}$ — (iii)

∴ Total energy of electron,

$E = k + U = -\frac{e^2}{8\pi\varepsilon_0 r}$ — (iv)

Due to this -ve energy, electron is bounded to nucleus, revolves around.

Giving energy to electron, r will increase.

$E = 0$, where, $r = \infty$ (free electron)

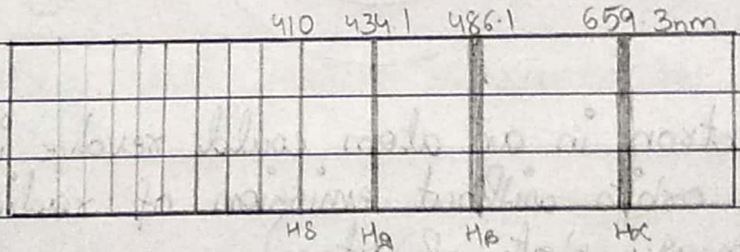
Note:
From eq (ii),

$$v = \frac{e}{\sqrt{4\pi\epsilon_0 m r}}$$

* Atomic spectra:

- Emission-
Due to excitation of atom, a light of particular wavelength is emitted and can be seen.
- Absorption-
If atoms are excited in presence of white light, it absorbs the same colour and a black line will appear.

* Balmer series:



$$\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n^2}\right] (n = 3, 4, 5 \ldots)$$
(R is Rydberg's constant, $R = 1.097 \times 10^7$)

* Lyman series:

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{n^2}\right] (n = 2, 3, 4 \ldots)$$
(For ultra violet rays)

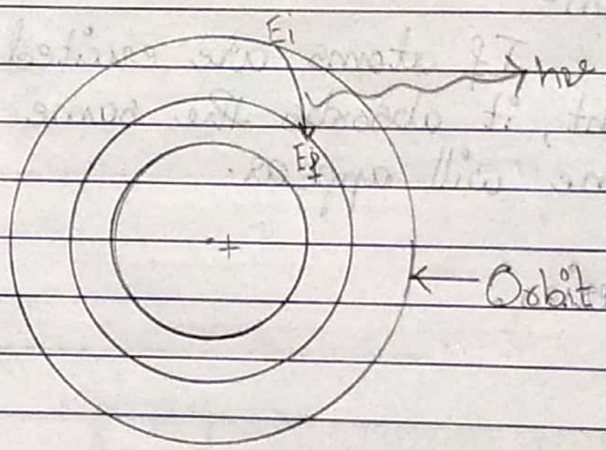
*** Paschen series:**

$$\frac{1}{\lambda} = R\left[\frac{1}{3^2} - \frac{1}{n^2}\right] \text{ where } n = 4, 5, 6.$$

*** Brackett's series:**

$$\frac{1}{\lambda} = R\left[\frac{1}{4^2} - \frac{1}{n^2}\right] \text{ where } n = 5, 6, 7 \ldots$$

*** Bohr's model and postulates:**



- An electron in an atom could revolve in certain stable orbits without emission of radial energy. (Stationary state of atom).
- Electrons revolve around nucleus only in those orbits for which the angular momentum is some integral multiple of $\left(\frac{h}{2\pi}\right)$, where h is Planck's constant ~~6.6×10~~

Planck's constant = $(6.62 \times 10^{-34}$ J).

$\therefore$ Angular momentum $= \frac{nh}{2\pi}$

- An electron may ~~T~~make a transition from one of its specified non-reacting orbit to another of lower energy. When it does so, a photon is radiated having energy equal to energy difference between initial and final state. $h\nu = E_i - E_f$

* Calculation for hydrogen atom:

Angular momentum, $L = mvr$ and $L = \frac{nh}{2\pi}$

$\therefore m v_n r_n = \frac{nh}{2\pi}$

But, we know that $v_n = \frac{e}{\sqrt{4\pi\varepsilon_0 m r}}$

Combining the two we get,

$v_n = \frac{1}{n}\frac{e^2}{4\pi\varepsilon_0\left(\frac{h}{2\pi}\right)}$ and ~~r_0~~ $r_n = \left(\frac{n^2}{m}\right)\left(\frac{h^2}{2\pi}\right)\frac{4\pi\varepsilon_0}{e^2}$

So, velocity in next orbit is fallen by $\frac{1}{n}$.

$r_1 = \frac{h^2\varepsilon_0}{\pi m e^2}$ and radius increases by n^2

$r_1 = a_0 = 5.29\times10^{-11}$ m for Bohr's model of hydrogen.

Now, energy of electron in stationary state of hydrogen atom is given by eq (iv).

$E_n = \frac{-e^2}{8\pi\varepsilon_0}\frac{m}{n^2}\left(\frac{2\pi}{n}\right)\frac{e^2}{4\pi\varepsilon_0}$

or $E_n = \frac{-me^4}{8n^2\varepsilon_0^2 h^2}$, by putting all values

$$E_n = \frac{-2.18 \times 10^{-18}\,J}{n^2} \quad \text{or} \quad E_n = \frac{-13.6\ eV}{n^2}$$

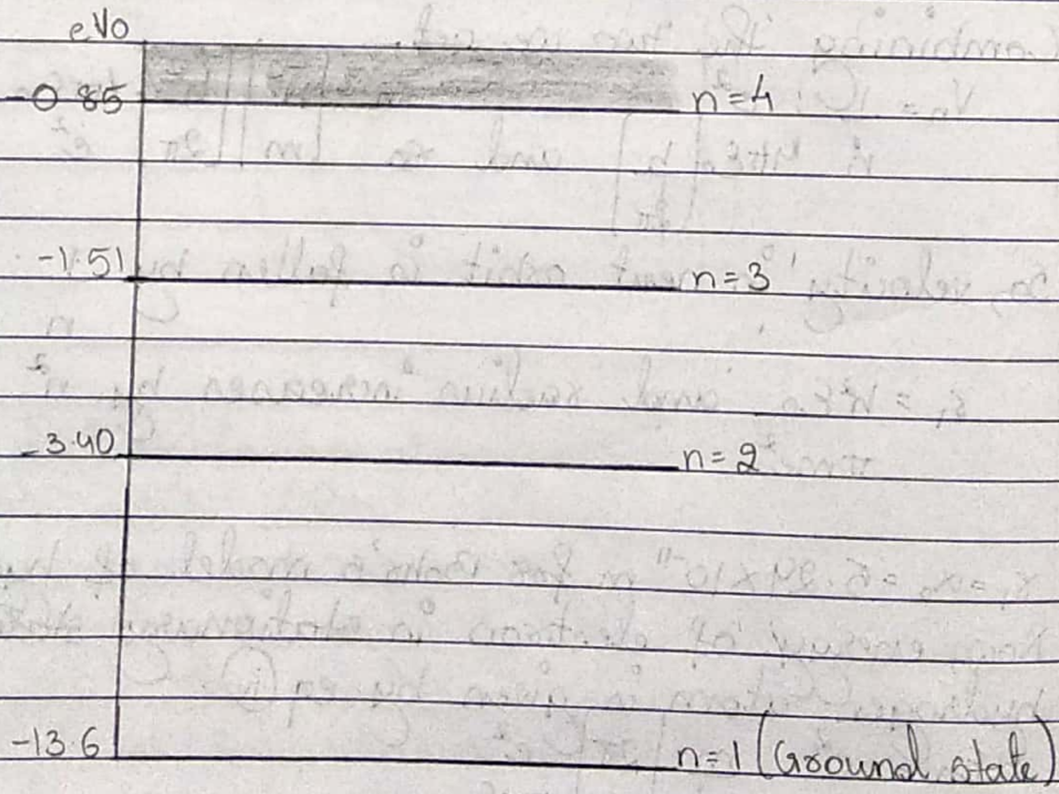
Note:
Highest energy level is 0 eV when $n = \infty$ ($r = \infty$).

* Energy level of electron in an atom:

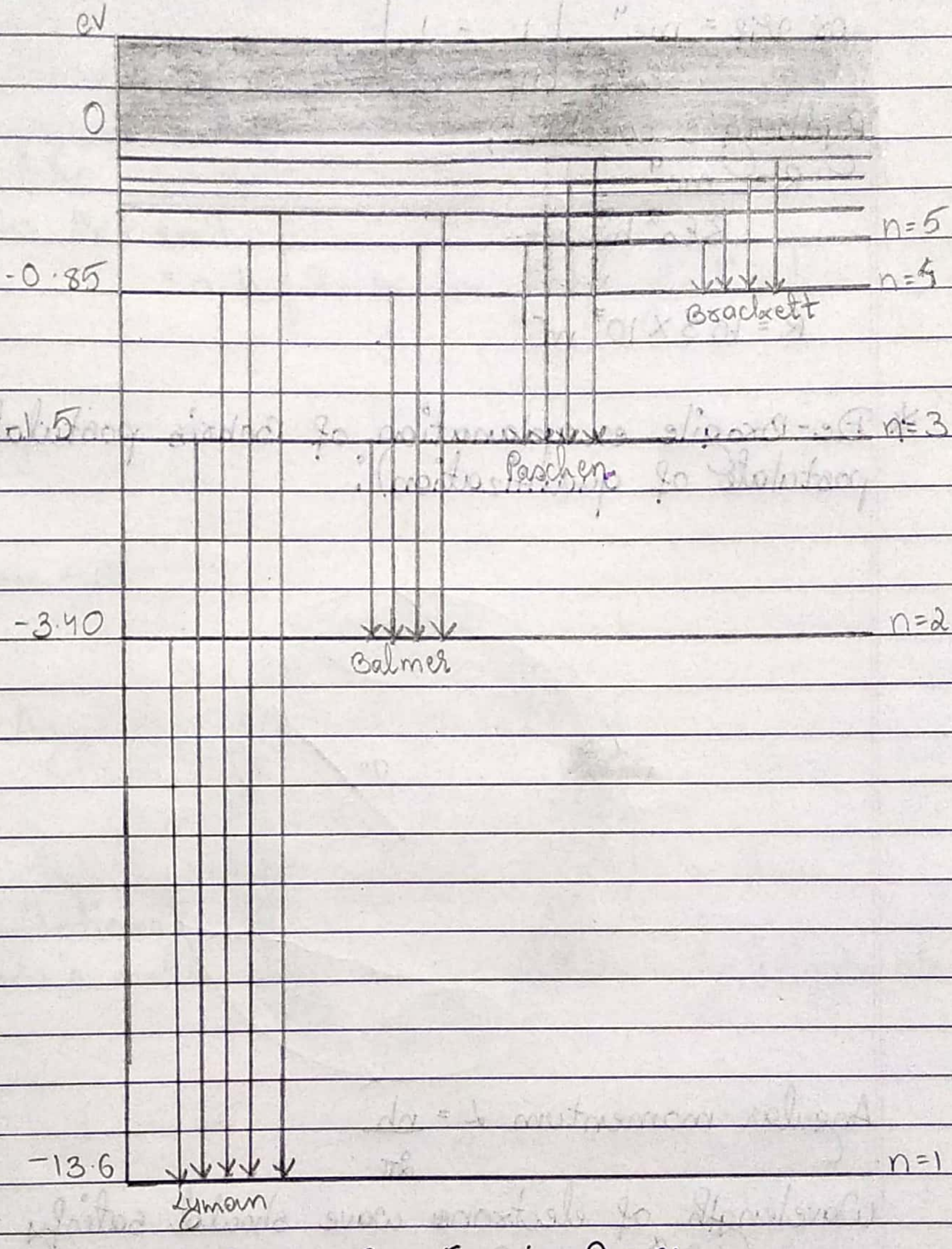
Energy of electron $E = h\nu$

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

$$= \frac{me^2}{8\pi^2 \varepsilon_0^2 n^2}$$



Energy level diagram of H-atom.



$E = h\nu$ or $\nu = \frac{E}{h}$ or $\frac{c}{\lambda} = \frac{E}{h}$ $\therefore \lambda = \frac{ch}{E}$

Difference of energy,

$$E_{if} = h\nu_{if} = \frac{me^4}{8\epsilon_0^2 h^2}\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

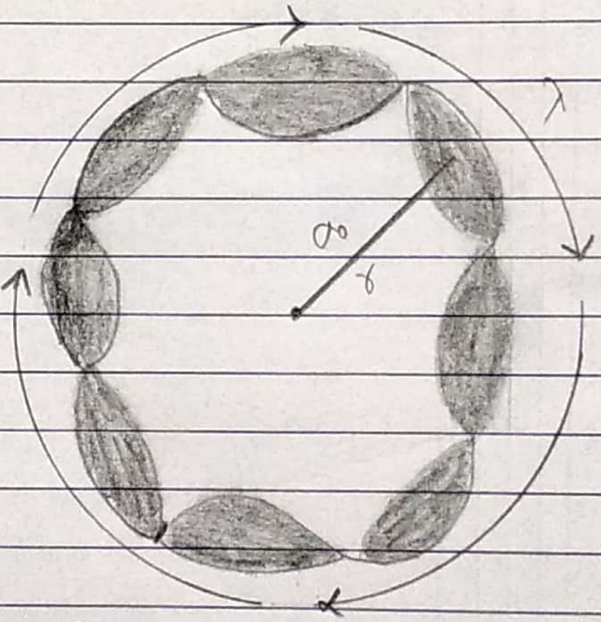
or $\nu_{if} = \frac{me^4}{8\varepsilon_0^2 h^3}\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$

Rydberg's constant,

$R = \frac{me^4}{8\varepsilon_0^2 h^x}$

$R = 1.03 \times 10^7 \ m^{-1}$

* De-Brogile explanation of Bohr's postulate (2nd postulate of quantization):



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

Wavelength of electron wave should satisfy relation,

$2\pi r_0 = n\lambda$

Condition for stationary wave,

$l = n\lambda$

Note:
Stationary waves mean waves which does not propagate energy.

Now, $2\pi r = n\lambda$

$= n \cdot \frac{h}{p}$ $\left[\lambda = \frac{h}{p}\right.$ for photon ejection$\left.\right]$

So, $2\pi r = \frac{nh}{mv}$ $(P = mv)$

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

$\therefore$ Angular momentum, $L = mvr = \frac{nh}{2\pi}$

$\therefore$ This is second postulate of Bohr's atom.

- Limitations:

Bohr's model is for hydrogen atom only (single atom)