Unit - 4

ATOM MODELS

- Limitations of Rutherford's atomic model.

→ It could not explain the stability of atoms because revolving electrons should lose energy and fall into the nucleus.

→ It could not explain the discrete line spectra of atoms.

→ It didn't specify how electrons are distributed around the nucleus or their energy levels.

Bohr's atom model. (1912) - Neil Bohr.

1. Electrons revolves around the nucleus in definite energy levels called orbits or shells in an atom without radiating energy.
2. As long as electron remain in a shell it never gains or losses energy.
3. The gain or loss of energy occurs within orbits only due to jumping of electrons from one energy level to another energy level.

* ~~atom~~ an electron jump only from a stationary higher energy orbit to one of lower energy.

$$\boxed{\text{Photon frequency } \nu = \frac{E_i - E_f}{h}}$$

E_i - initial energy

E_f = final orbit of energy.

h - planks co

4. An electron can revolve round the nucleus only in those allowed or permissible orbits for which [the angular momentum of the electron is an integral multiple of $h/2\pi$.]

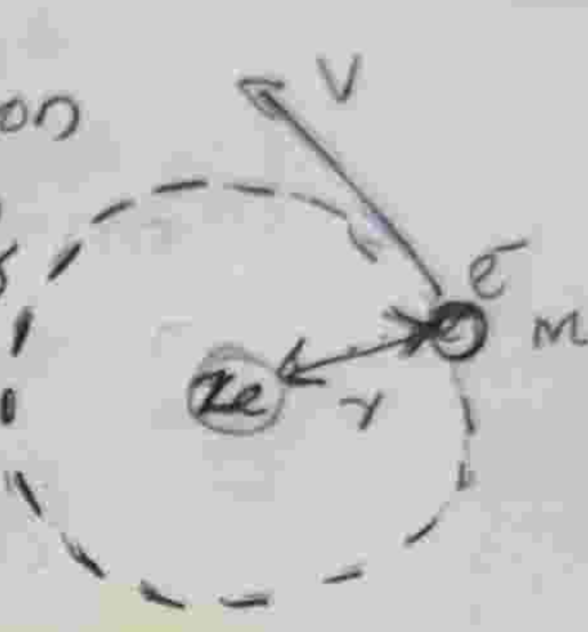
$$\boxed{mvr = \frac{nh}{2\pi}}$$

mvr - angular moment (ω)
n = 1, 2, 3, 4, ...

Application of Bohr atom model.

① Derivation of Radius of an orbit of an atom.

Consider an atom having an electron e⁻ revolving around a nucleus of charge Ze. Let m be the mass, r the radius of the orbit and v is the velocity of the revolving electron.



Acc, to coloumb's law, Electrostatic force b/w nucleus and electron;

Fcm

$$F_c = \cancel{4\pi}\frac{q_1 q_2}{4\pi\varepsilon_0 r^2} = \frac{Ze \cdot e}{4\pi\varepsilon_0 r^2}$$

$$= \frac{Ze^2}{4\pi\varepsilon_0 r^2}.$$

Centrifugal force acting on the electron;

$$= \frac{mv^2}{r}$$

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

$$mv^2 = \frac{Ze^2}{4\pi\varepsilon_0 r}.$$

$$r \neq \frac{Ze^2}{\ldots^2} \qquad r = \frac{Ze^2}{4\pi\varepsilon_0 mv^2}$$

~~mvr =~~

Acc, to Bohr's postulate.

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

$$v = \frac{nh}{2\pi m r}$$

$$v^2 = \frac{n^2h^2}{4\pi^2 m^2 r^2}$$

$$r = \frac{Ze^2}{4\pi\varepsilon_0 m} \times \frac{4\pi^2 m^2 r^2}{n^2 h^2}$$

$$\frac{1}{1} = \frac{Ze^2 \pi m r}{\varepsilon_0 n^2 h^2}$$

$$Ze^2 \pi m r = \varepsilon_0 n^2 h^2$$

$$r = \frac{\varepsilon_0 n^2 h^2}{Ze^2 \pi m.}$$

$$r_n = \frac{n^2 h^2 \varepsilon_0}{\cancel{Z} \pi e^2 m} \quad (Z=1)$$

The radii of the orbits are in the ratio of 1:4:9:16.

The radius of first orbit for hydrogen atom

$$r_1 = \frac{1^2 \times (6.626\times10^{-34})^2 (8.85\times10^{-12})}{\pi \times (1.6\times10^{-19})^2 \times (9.11\times10^{-31})}$$

$$= 0.053\,nm$$

This called **Bohr radius**.

$$r_1 = 0.053.$$

$$r_2 = 2^2 r_1$$

$$= 4 \times 0.053 = 0.212\,nm$$

$$\boxed{r_n = n^2 r_1}$$

Derivation of Energy of an Electron in an orbit.

The energy of an electron in an orbit is the sum of its potential and kinetic energy.

$$E_T = K.E + PE.$$

$$E_T = \frac{1}{2}mv^2 + \left[-\frac{Ze^2}{4\pi\varepsilon_0 r}\right]$$

$$E_T = \frac{1}{2}mv^2 - \frac{Ze^2}{4\pi\varepsilon_0 r}$$

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

$$E_T = \frac{Ze^2}{2 \cdot 4\pi\varepsilon_0 r} - \frac{Ze^2}{4\pi\varepsilon_0 r}$$

$$E_n = \frac{Ze^2}{8\pi\varepsilon_0 r} - \frac{Ze^2}{4\pi\varepsilon_0 r}$$

$$E_n = \frac{Ze^2}{4\pi\varepsilon_0 r}\left[\frac{1}{2} - 1\right]$$

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

$$E_n = \frac{-Ze^2}{8\pi\varepsilon_0 r} \times \frac{Ze^2\pi m}{\varepsilon_0 n^2 h^2}$$

$$E_n = \frac{-Z^2e^4 m}{8\varepsilon_0^2 n^2 h^2}$$

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

$$\boxed{E_n = \frac{-me^4}{8\varepsilon_0^2 h^2}\left[\frac{1}{n^2}\right]}$$

Calculation of wave number

If an electron jumps from an outer initial orbit n_2 of higher to an inner orbit n_1 of lower energy, the frequency of the radiation emitted is given by

$$\nu = \frac{(E_{n_2} - E_{n_1})}{h}$$

$$E_{n_1} = \frac{-me^4}{8\varepsilon_0^2 h^2}\left[\frac{1}{n_1^2}\right], \quad E_2 = \frac{me^4}{8\varepsilon_0^2 h^2}\frac{1}{n_2^2}$$

$$\nu = \frac{\left[\frac{-me^4}{8\varepsilon_0^2 h^2}\frac{1}{n_2^2} - \frac{-me^4}{8\varepsilon_0^2 h^2}\frac{1}{n_1^2}\right]}{h}$$

$$\nu = \frac{me^4}{8\varepsilon_0^2 h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$$R = \frac{me^4}{8\varepsilon_0^2 ch^3}$$

$$\bar{\nu} = \frac{\nu}{c}$$

$$= \frac{me^4}{8\varepsilon_0^2 ch^3}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$\frac{me^4}{8\varepsilon_0^2 ch^3}$ = Rydberg constant. R.

$$\boxed{\bar{\nu} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]}$$

Spectral series of hydrogen atom.

1. Lyman Series
   - occurs in the ultraviolet region of the electromagnetic spectrum.
   - max: wavelength ⇒ 121 nm
     min: wavelength ⇒ 91 nm.

$$\boxed{\frac{1}{\lambda} = R_H\left(\frac{1}{1^2} - \frac{1}{n_f^2}\right)}$$

2. Balmer series
   - occurs in the visible region of the electromagnetic spectrum
   - max: wavelength ⇒ 656 nm
     min: wavelength ⇒ 365 nm.

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

3. Paschen Series
   - occurs in the infrared region of the electromagnetic spectrum.
   - max wavelength ⇒ 1875 nm
     min wave length ⇒ 821 nm

$$\frac{1}{\lambda} = R_H\left(\frac{1}{3^2} - \frac{1}{n_f^2}\right)$$

4) Brackett Series

- occurs in the infrared region of the electromagnetic spectrum.
- max: wavelength ⇒ 4051 nm $\frac{1}{\lambda} = R_H\left(\frac{1}{4^2} - \frac{1}{n_f^2}\right)$
- min: wavelength ⇒ 1458 nm

5) Pfund series

- occurs ~~tot~~ in the infrared region of the electromagnetic spectrum.
- max: wavelength ⇒ 7460 nm $\left[\frac{1}{\lambda} = R_H\left(\frac{1}{5^2} - \frac{1}{n_f^2}\right)\right]$
- Min wavelength ⇒ 2280 nm.

Energy-level diagram

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

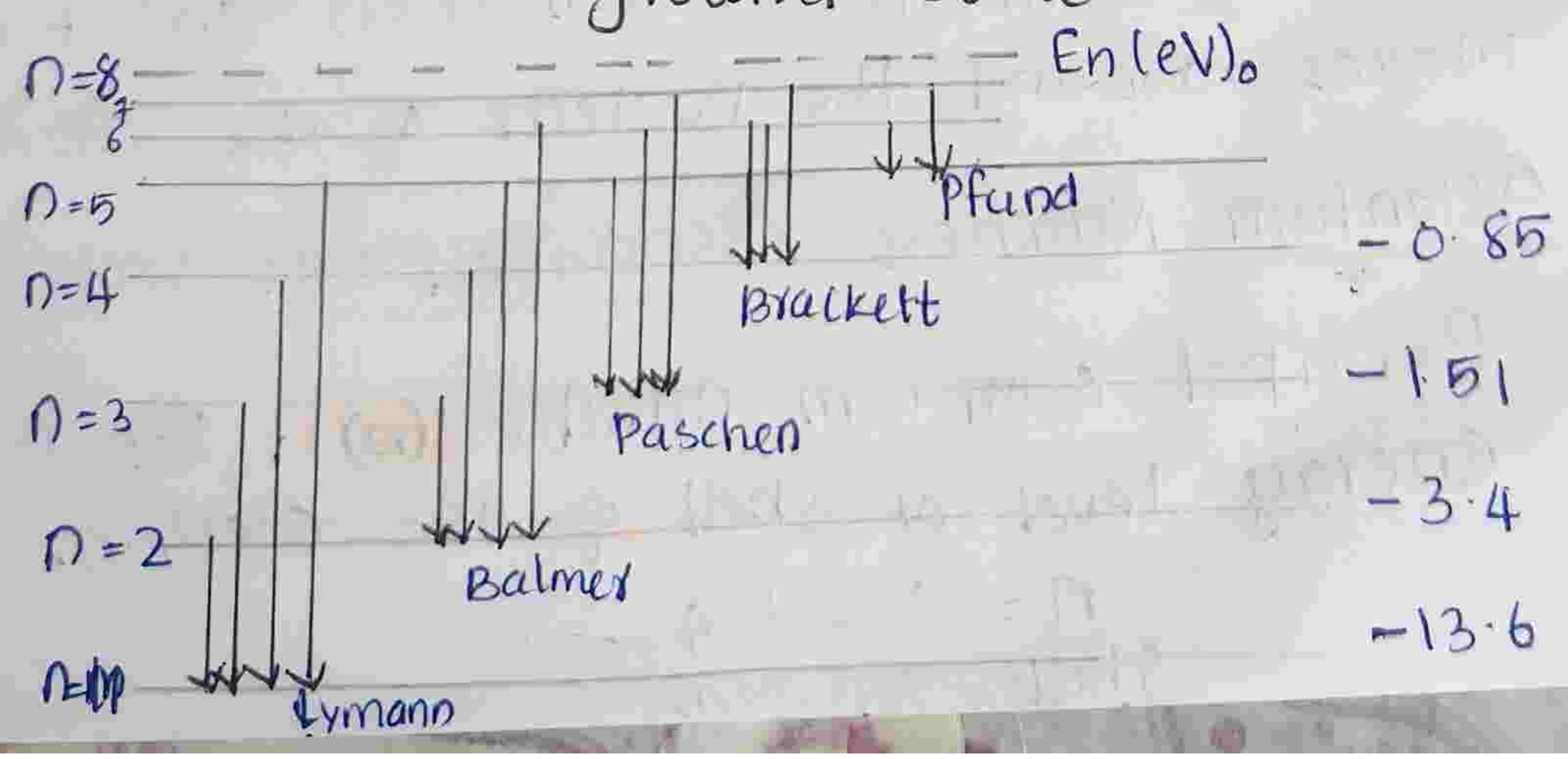
for hydrogen atom.

$(z=1)$ $\frac{me^4z^2}{8\varepsilon_0^2 h^2} = \frac{(9.11\times10^{-31})(1.9\times10^{-19})^4\times(1)^2}{8(8.85\times10^{-12})^2(6.625\times10^{-34})^2}$

$= 21.76\times10^{-19}J$

$E_1 = \frac{21.76\times10^{-19}}{1.6\times10^{-19}} eV = 13.6eV$

E_1 → normal or ground state.



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Vector atom model

Vector Atom model was introduced to explain the fine structure of spectral lines, Zeeman and Stark effects, and the distribution of electrons around the nucleus.

① Bohr's model could explain only the hydrogen spectrum. It couldn't explain the fine structure of spectral lines.

② Bohr and Sommerfeld models could not explain: Zeeman effect and Stark effect.

③ Bohr's model couldn't explain the distribution of electrons around the nucleus.

1. Spatial quantization.

Spatial quantization is the phenomenon in which the angular momentum vector of an electron can have only certain discrete orientation in space.

- Acc, to quantum theory both magnitude and direction of the orbits are quantised.

2. Spinning of electron

- Electron spins about its own axis and it also moves around the nucleus of the atom.

Quantum Numbers Associated with Vector atom model

1. Principal quantum number (n) : Rep main energy level or shell of the electron.

$n = 1, 2, 3, 4, \ldots$

(Shells = K, L, M, N, ..)

2. Azimuthal (orbital) Quantum No:- Rep the shape of the orbital and orbital angular momentum.

[Values: $l = 0$ to $(n-1)$] l

l	Subshell
0	s
1	p
2	d
3	f.

3. Magnetic Quantum No:- Rep the orientation of the orbital in space. (spatial quantization) m_l M

[Values: $m = -l$ to $+l$]

4. Spin Quantum Number (ms): Rep the spin of the electron.

[Values: $+1/2$ (spin up) & $-1/2$ (spin down)]

Paulis Exclusion Principle.

- Pauli's Exclusion Principle states that no two electrons in an atom can have the same set of four quantum no:s ∴ an orbital can accomodate a max of two electrons with oppo. spins.

→ Explains the arrangment of electron in atoms.

→ Helps determine electronic configuration.

→ Explains why an orbital can contain only two electrons.