# Atomic Structure

| Particle | Mass | charge | Specific charge |
|---|---|---|---|
| electron | $9.1 \times 10^{-31}$ kg | $-1.6 \times 10^{-19}$ C | $1.7588 \times 10^{11}$ C/kg |
| Proton | $1.673 \times 10^{-27}$ kg | $1.6 \times 10^{-19}$ C | |
| Neutron | $(\simeq m_p)\ 1.675 \times 10^{-27}$ kg | 0 | |
| $\alpha$ particle | $\simeq 4 \times m_p$ | $2 \times 1.6 \times 10^{-19}$ C. | |

## Properties of charge

$q_1 \overset{r}{\text{———}} q_2$

*Force acting b/w 2 charges $q_1, q_2$ at distance $r$, $F = K\dfrac{q_1 q_2}{r^2}$

K = 1 in CGS system

$K = 9 \times 10^9$ in SI

*Potential E, $U = K\dfrac{q_1 q_2}{r}$

$\boxed{F = -\dfrac{dU}{dr}}$

* $1\ eV = 1.6 \times 10^{-19}$ J.

## Characteristics of cathode & Anode rays

*cathode rays nature & specific charge ⇒ Independs on nature of gas

*Anode rays " " ⇒ dependent on nature of gas.

* $R_{atom} = 10^{-10}$ m, $R_{Nucleus} = 10^{-15}$ m (range)

* $R_{Nucleus} = R_0 (A)^{1/3}$ ⇒ $R_0 = \frac{4}{3} \times 10^{-15}$ m

A ⇒ mass no.

## Distance of closest approach

$q_1$ ———————— $q_2$

Infinite distance

PE = 0 $KE = \frac{1}{2}mv^2$

Distance of closest approach ($r_{closest}$)

KE = 0

$PE = \dfrac{K q_1 q_2}{r_{closest}}$

Total E conserved, so

$$\frac{1}{2}mv^2 = \frac{K q_1 q_2}{r_{closest}} \qquad \left[K = \frac{1}{4\pi\epsilon_0}\right]$$

## Representation of atom

$^{A}_{Z}X$

Z ⇒ Atomic no = no. of P = no. of $\bar{e}$ in Neutral atom

A ⇒ mass no = no. of P + no. of n

no. of n = A − Z

| ~~Isot~~ | Same no. of: | different no. of |
|---|---|---|
| Isotopes | Z (protons) | A & no. of neutrons. |
| Isobars | A (nucleons) | Z (protons) |
| Isotones | (A−Z) (neutrons) | A, Z |
| Isodiaphers | A − 2Z | |
| Isosters | no. of atoms & $\bar{e}$ | |
| Isoelectronic | no. of $\bar{e}$ | |

## Properties of wave

* $\bar{\nu}$ (wave number) $= \frac{1}{\lambda}$    λ ⇒ wavelength.
* $\nu$ (frequency) $= \frac{c}{\lambda}$    $T = \frac{1}{\nu}$

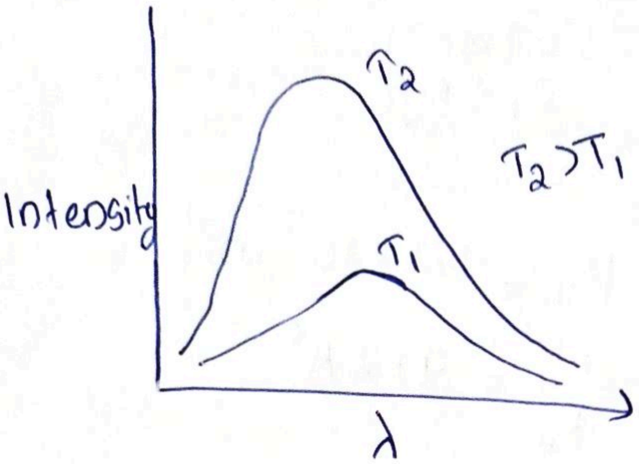
## Electromagnetic spectrum

↑sing λ & ↓sing ν →

| Cosmic rays | γ rays | X rays | UV | Visible | IR | Micro wave | Radio wave |
|---|---|---|---|---|---|---|---|
| | | | | VIBGYOR 380 — 760nm | | | |

* EM waves contain Electrical field & Magnetic field which are perpendicular to each other & ⊥er to the direction of motion.

## Black Body Radiation




## Planck's quantum theory

$$\boxed{E_{photon} = h\nu = \frac{hc}{\lambda} \quad h = 6.626 \times 10^{-34}\ JS \qquad \text{total } E = \text{no. of photon} \times E_{photon}}$$

* one photon can excite one $\bar{e}$ & will break only one bond.

$$\boxed{* \quad \frac{E_1}{E_2} = \frac{\nu_1}{\nu_2} = \frac{\lambda_2}{\lambda_1}}$$

* $E_{photon} = \frac{hc}{\lambda} = \frac{1242}{\lambda \text{ in nm}}\ eV$

$$\boxed{* \quad 1\ eV/\text{atom} = 96.4\ KJ/mol}$$

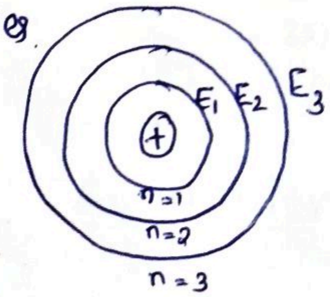
approx

$$\boxed{E_{photon} = \frac{1240}{\lambda \text{ in nm}}\ eV \qquad E_{photon} = \frac{2 \times 10^{-16}}{\lambda \text{ in nm}}\ J}$$

## Boha's Model of atom

* As distance increases E. of orbit ↑ses.

$E_1 < E_2 < E_3 \;\ldots$ at $\infty$, $E = 0$




* Angular momentum is quantized.

$$\boxed{mvr = \frac{nh}{2\pi}} \qquad n = 1, 2, 3 \ldots$$

* $$\boxed{\underbrace{\frac{mv^2}{r}}_{\text{centripetal F}} = \underbrace{\frac{kZe^2}{r^2}}_{\text{Electrostatic F}}}$$

* E absorbed / released [$n_2 \rightarrow n_1$ transition]

$\Delta E = E_{n_2} - E_{n_1} = \frac{hc}{\lambda}$

* Ground state (GS): lowest energy state ($n=1$)
* Excited state (ES): All other state

1st ES $\Rightarrow n = 2$

2nd ES $\Rightarrow n = 3$

$x^{th}$ ES $\Rightarrow n = x + 1$

* E released & absorbed in the form of photon.

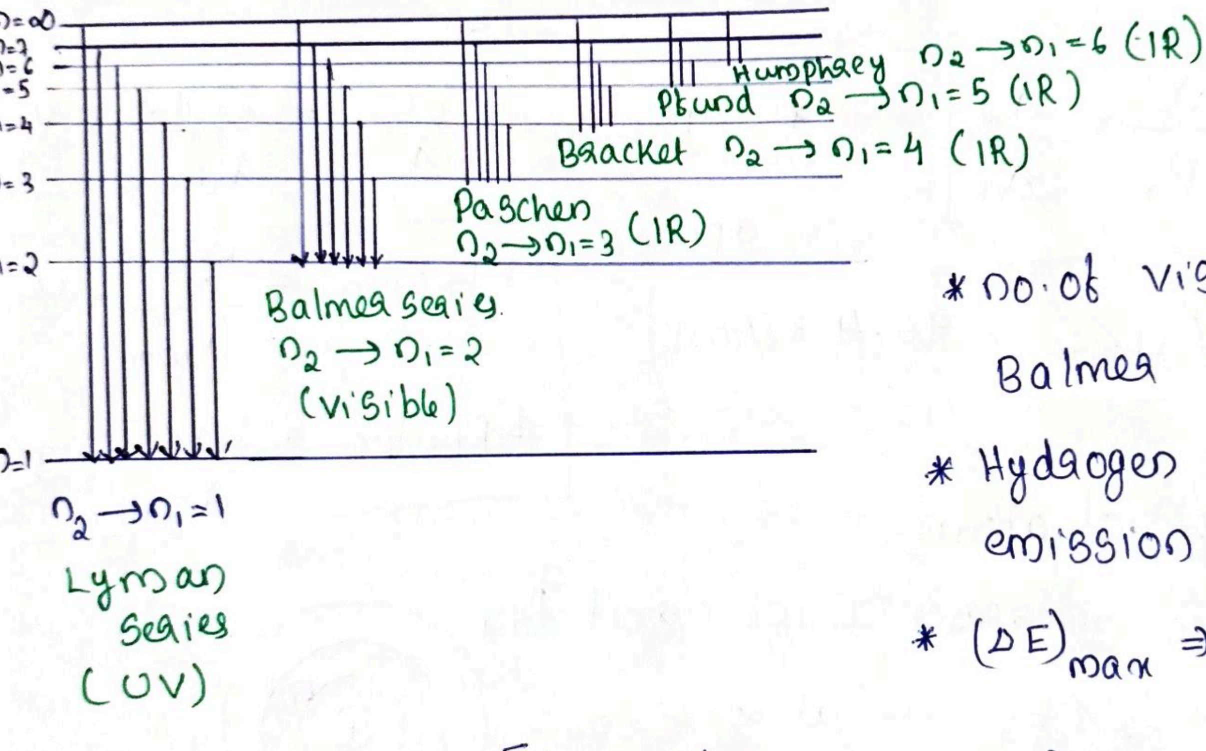
**Hydrogen Spectra & Rydberg equation**

$$\boxed{\bar{\nu} = \frac{1}{\lambda} = R_H\, Z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] \quad \text{where } n_1 < n_2}$$

$R_H = 1.09677 \times 10^7\ m^{-1}$

$R_H \simeq 1.1 \times 10^7\ m^{-1}$

$\frac{1}{R_H} = 912\ A^o$




$n_2 \to n_1 = 1$
Lyman Series (UV)

* no. of visible lines in Balmer = 4

* Hydrogen spectra is emission spectra.

* $(\Delta E)_{max} \Rightarrow$ then min $\lambda$, max $\nu$ & $\bar{\nu}$

$(\Delta E)_{min} \Rightarrow$ then max $\lambda$, min $\nu$ & $\bar{\nu}$

* Maximum $\lambda$ [transition $n_1 + 1 \to n_1$]

* minimum $\lambda$ [transition $\infty \to n_1$]

$$\boxed{\lambda_{min} = \frac{n_1^2}{R_H Z^2}}$$

* In general

$$\boxed{\lambda = \frac{n_1^2\, n_2^2}{R_H Z^2 (n_2^2 - n_1^2)}}$$

# Photoelectric effect

$$\boxed{\begin{array}{c} h\nu = h\nu_0 + \frac{1}{2}mv^2 \\ \text{Incident E} = \text{threshold E} + \text{max. Kinetic E} \end{array}}$$

$\phi = h\nu_0$

$\phi \Rightarrow$ threshold E or Work function [Minimum E required to eject $\bar{e}$]

$\nu_0 \Rightarrow$ threshold frequency (minimum frequency required to eject $\bar{e}$)

$\lambda_0 \Rightarrow$ threshold wavelength (max. wavelength required to remove $\bar{e}$)

* KE depends on Incident photons E

  $KE \propto \nu$ (Incident frequency)

* KE Independent on Intensity of light (no. of photons)

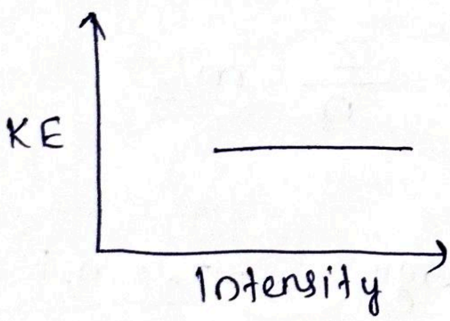
* Intensity of light ↑ses, Photocurrent ↑ses.

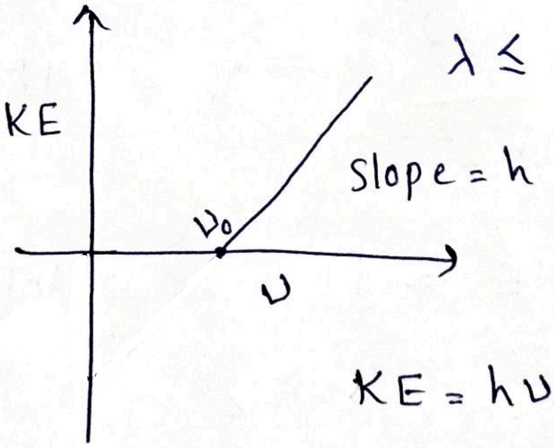
* Photocurrent is independ on frequency.

* Photoelectric effect is observed, when $h\nu \geq h\nu_0$

  $\nu \geq \nu_0$

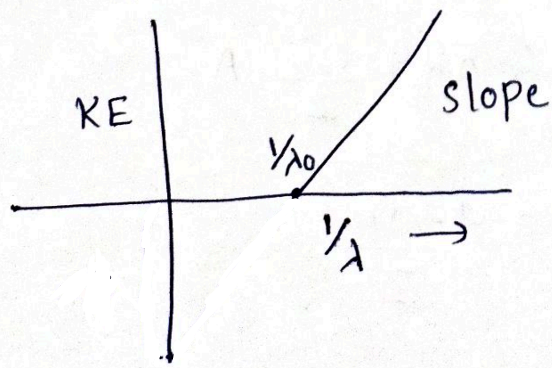
  $\lambda \leq \lambda_0$



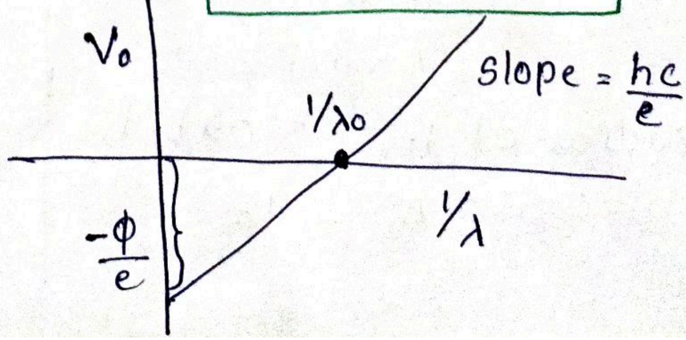

$KE = h\nu - \phi$

$KE = \frac{hc}{\lambda} - \phi$




* Stopping potential ($V_0$)

$$\boxed{eV_0 = KE_{max}}$$



* no. of different photons / spectral lines emitted during

$n_2 \to n_1$ transition $= \dfrac{(n_2-n_1)(n_2-n_1+1)}{2}$

$n_2 - n_1 = \Delta n$ $\quad = \dfrac{\Delta n(\Delta n+1)}{2}$

* when $n \to 1$ (GS) transition $\Rightarrow \dfrac{n(n-1)}{2}$

Spectral lines in Lyman $\Rightarrow n-1$ Balmer $\Rightarrow n-2$

Paschen $\Rightarrow n-3$ Bracket $\Rightarrow n-4$

Pfund $\Rightarrow n-5$ Humphrey $\Rightarrow n-6$.

* For a single isolated atom (single $\bar{e}$) [$n \to 1$ transition]

minimum no. of lines / photons $= 1$

Maximum " " $= n-1$

<u>Bohr's model</u>

* $V_n = \dfrac{2\pi K Z e^2}{nh}$ $\qquad V_n = 2.18 \times 10^6 \dfrac{Z}{n}$ m/s.

* $TE = -KE = \dfrac{PE}{2}$ $\Rightarrow$ total energy $E_n = \dfrac{-2\pi^2 m K^2 Z^2 e^4}{n^2 h^2}$.

$E_n = -2.18 \times 10^{-18} \dfrac{Z^2}{n^2}$ J

$E_n = -13.6 \dfrac{Z^2}{n^2}$ eV.

* $r_n = \dfrac{n^2 h^2}{4\pi^2 m K Z e^2}$ $\qquad r_n = 0.529 \dfrac{n^2}{Z}$ A°

radius of H, 1st orbit $\qquad r_n = \dfrac{a_0 n^2}{Z}$

$= 0.529$ A° $= a_0$

## Debroglie's Hypothesis [Dual nature of matter]

* Wave associated with matter (Particle) K/a matter wave [It is different from EM waves]

Wavelength associated with matter K/a debroglie wavelength

$$\boxed{\lambda_{dB} = \frac{h}{P} \qquad \lambda = \frac{h}{mv}}$$

$$KE = \frac{P^2}{2m}$$

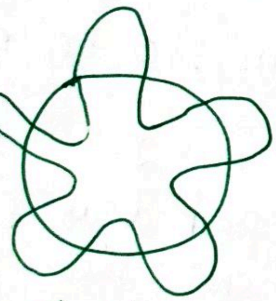
$$P = \sqrt{2mKE}$$

$$KE = q \times V$$

$\Downarrow$ voltage

$$\boxed{\lambda = \frac{h}{\sqrt{2mKE}} = \frac{h}{\sqrt{2mq \times V}}}$$

$$\boxed{\text{For } \bar{e},\ \lambda = \sqrt{\frac{150}{V}}\ A^{o}} \Rightarrow \lambda = \frac{12.25}{\sqrt{V}}\ A^{o}$$



Standing wave

* no. of waves in $n^{th}$ orbit $= n$

$$\boxed{2\pi r_n = n\lambda}$$

$$2\pi \frac{a_0 n^2}{Z} = n\lambda$$

$$\boxed{\lambda = \frac{2\pi a_0 n}{Z}}$$

## Heisenberg's Uncertainity principle

$$\boxed{\Delta x \cdot \Delta p \geq \frac{h}{4\pi} \qquad \Delta x \cdot \Delta v \geq \frac{h}{4\pi m}}$$

$$\boxed{\frac{\Delta P}{P} = \frac{\Delta \lambda}{\lambda}}$$

$\lambda \Rightarrow$ debroglie wavelength.

% error in position $= \frac{\Delta x}{x} \times 100$.

% error in momentum $= \frac{\Delta P}{P} \times 100$

% error in velocity $= \frac{\Delta V}{V} \times 100$

# Wave Mechanical Model of atom

$\psi \Rightarrow$ wave $f^n$ [has no physical significance]

$\psi^2 \Rightarrow$ Probability density

n, l, m $\Rightarrow$ derived from Schrodinger equation

s $\Rightarrow$ arbitrarly assumed Quantum no.

**Quantum numbers** $\Rightarrow$ 4 Quantum numbers [n, l, m & s]

## Principal Quantum number (n)

$\Rightarrow$ Represents Shell

$\Rightarrow$ Represents Size, energy & velocity of $\bar{e}$

$\Rightarrow$ n varies from $1 \rightarrow \infty$

n = 1 2 3 4

K L M N

$\Rightarrow$ no. of $\bar{e}$ in nth shell $= 2n^2$

orbit Angular momentum $= n\frac{h}{2\pi}$

## Azimuthal quantum no (l)

$\Rightarrow$ Represents Subshell

$\Rightarrow$ Represent 3D shape of subshell & orbital, orbital angular momentum.

$\Rightarrow$ l varies from : 0 to n-1

| l = | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| | s sub shell | p sub shell | d sub shell | f sub shell |

orbital angular momentum

$= \sqrt{l(l+1)}\frac{h}{2\pi}$

no. of $\bar{e}$ in subshell $= 2(2l+1)$

## Magnetic quantum no (m)

$\Rightarrow$ Represent orbital

$\Rightarrow$ Represent spatial orientation of orbital

$\Rightarrow$ m can have values $-l$ to 0 to $+l$

$\Rightarrow$ no. of orbitals in subshell $= 2l+1$

$\Rightarrow$ no. of $\bar{e}$ in one orbital = 2

$\Rightarrow$ no. of orbitals in nth shell $= n^2$

## Spin quantum no (s)

$s = +\frac{1}{2}$ & $-\frac{1}{2}$

## Aufbau's principle (n+l) rule.

$E \propto n+l$ [For multi $\bar{e}$ system]

Same (n+l) value for two subshell ⇒ lower the n value lower the E

E order:

(1s) (2s 2p) (3s 3p) (4s 3d 4p) (5s 4d 5p) (6s 4f 5d 6p) (7s 5f 6d 7p) (8s 5g 6f 5d 8p)

* $E \propto n$ [For one $\bar{e}$ system] ⇒ i.e., independent of l.

* Magnetic moment $= \sqrt{n(n+2)}$ BM  n ⇒ no. of unpaired $\bar{e}$

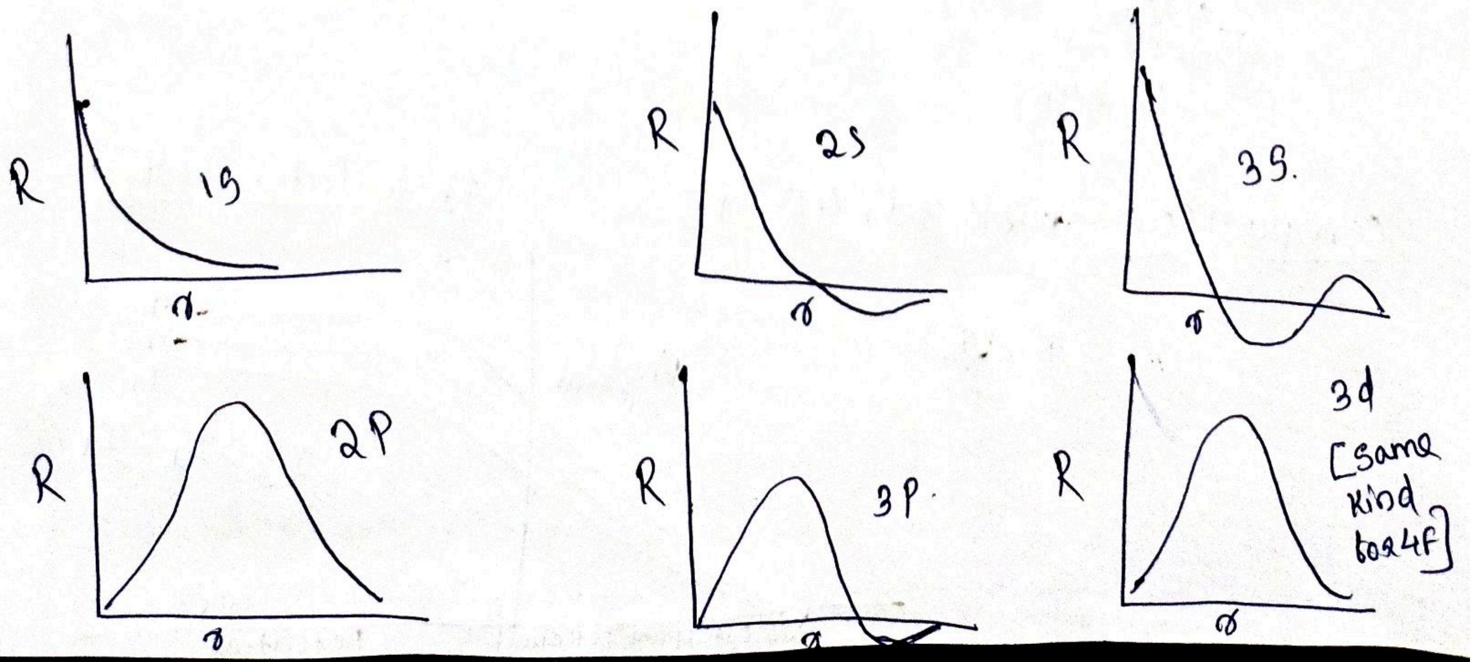
* IE $= 13.6\, Z^2$ eV.

* no. of (spherical) radial node $= n-l-1$

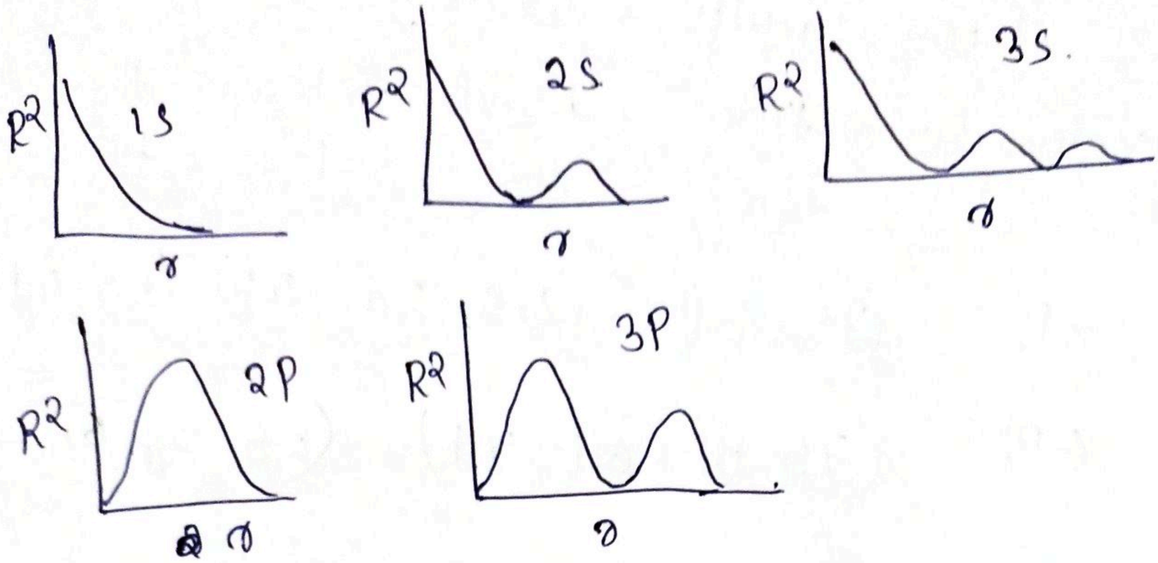
no. of angular node $= l$

no. of total node $= n-1$

Radial wave fn (R) vs r

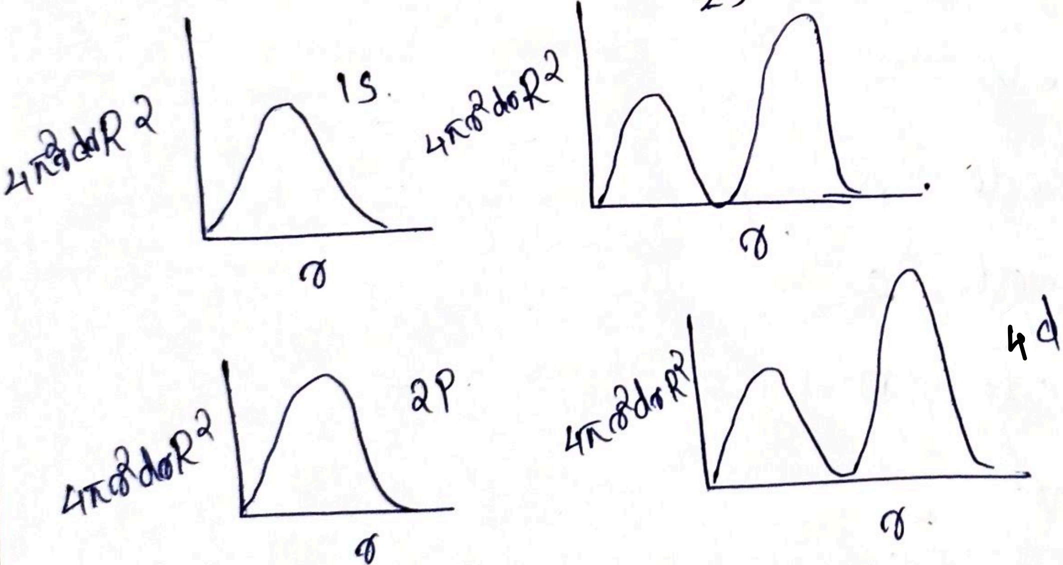


$R^2$ vs $r$




[Same kind for 3d & 4f]

$4\pi r^2 dr\, R^2$ vs $r$




[~~Same~~ Similar as 3d & 4f]

comparison * 2P, 3d, 4F, 1S.

* ~~1s~~

Photoelectric effect