ATOMIC STRUCTURE

Constants	Symbol	SI Value	
Speed of light in vaccum	c	2.99×10^8 m/s	2.99×10^{10} cm/s
Proton & electron charge	e	1.60×10^{-19} C	4.8×10^{-10} esu
Permittivity of vaccum	ε_0	8.85×10^{-12} $C^2/N\text{-}m^2$	
Avogadro constant	N_A	6.02×10^{23} mol^{-1}	6.02×10^{23} mol^{-1}
Electron rest mass	m_e	9.10×10^{-31} kg	0.000548 amu
Proton rest mass	m_P	1.67×10^{-27} kg	1.00757 amu
Neutron rest mass	m_n	1.67×10^{-27} kg	1.00893 amu
Planck constant	h	6.62×10^{-34} J s	6.62×10^{-27} erg s
Bohr magneton(BM)	β_e	9.27×10^{-24} J/T	
Gas constant	R	8.3145 J/mol-K	0.0821 atm-lit / mol / K
Boltzmann constant	k	1.38×10^{-23} J/K	1.30×10^{-16} erg/K
Gravitional constant	G	6.67×10^{-11} $m^3/kg\text{-}s^2$	6.67×10^{-8} $cm^3/g\text{-}s^2$

Energy Conversion Factors

1 erg = 10^{-7} J

1 cal = 4.184 J

1 eV = 1.602177×10^{-19} J = 1.602177×10^{-12} erg = 23.0605 kcal/mol

Greek Alphabet

Alpha	A	α	Beta	B	β
Gamma	Γ	γ	Delta	Δ	δ
Epsilon	E	ε	Zeta	Z	ζ
Eta	H	η	Theta	Θ	θ
Iota	I	ι	Kappa	K	κ
Lambda	Λ	λ	Mu	M	μ
Nu	N	ν	Xi	Ξ	ξ
Omicron	O	o	Pi	Π	π
Rho	P	ρ	Sigma	Σ	σ
Tau	T	τ	Upsilon	Y	υ
Phi	Φ	ϕ	Chi	X	χ
Psi	Ψ	ψ	Omega	Ω	ω

KEY CONCEPT

STRUCTURE OF ATOM

1. Rutherford's Model

(a) Electrons, protons & neutrons are the most important fundamental particles of atoms of all elements (Except hydrogen)

(b) ${}_{Z}X^{A}$, Mass number (A) = Atomic number (Z) + number of neutrons (n)

(c) $R_n = R_1 (A)^{1/3}$, $R_1 = 1.33 \times 10^{-13}$ cm A = mass number

(d) $\frac{1}{2} m_\alpha v_\alpha^2 = K \frac{Z.2e}{r}$; **r** = distance of closest approach , v_α = initial velocity of a α-particle

2. Light

(a) Photon is considered massless bundle of energy.

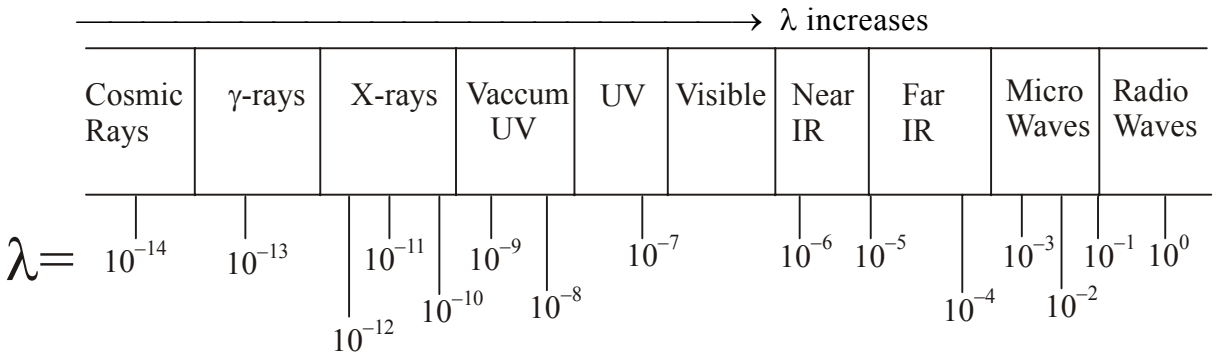
(b) $E = mc^2$

(c) $E_{photon} = h\nu = hc/\lambda = hc\,\bar{\nu}$

(d) $E = \frac{hc}{\lambda} \cong \frac{1240\,eV.nm}{\lambda}$

(e) Quantum efficiency or Quantum Yield $= \frac{\text{no. of molecules reacting}}{\text{no. of quanta absorbed}}$

3. Eleectromegnetic Spectrum



Ex.1. Arrange the particle in their increasing order of specific charge ratio.

(a) e^-, P, n, α-particle ***(b) Na^+, Li^+, F^-, Mg^{2+}, Al^{3+}***

Sol. *(a)* $\left(\frac{e}{m}\right)_e = \frac{1e}{\left(\frac{1}{1836}\right)amu}$

$\left(\frac{e}{m}\right)_P = \frac{1}{1} = 1 = \frac{1e}{1amu}$

$\left(\frac{e}{m}\right)_n = \frac{0}{1} = 0 = \frac{0e}{1amu}$

$\left(\frac{e}{m}\right)_\alpha = \frac{2}{4} = \frac{1}{2} = \frac{2e}{4amu}$

Ans. $n < \alpha < p < e^-$

(b) $Na^+ = \frac{1}{23}$; $Li^+ = \frac{1}{7}$; $F^- = \frac{1}{19}$; $Mg^{2+} = \frac{2}{24} = \frac{1}{12}$; $Al^{3+} = \frac{3}{27} = \frac{1}{9}$

$Na^+ < F^- < Mg^{2+} < Al^{3+} < Li^+$

Ex.2. Which of the following pairs have same specific charge $\left(\frac{e}{m}\right)$ ***?***

(a) electron & proton ***(b) electron & positron*** ***(c) proton & positron***
(d) proton & deutron ***(e) α-particle & deutron***

Answer. b, e

Ex.3. Through what potential difference an α-particle should be accelerated to have speed 5×10^6 ***m/s.***

Sol. : $qV = \frac{1}{2}mv^2$

$$(2 \times 1.6 \times 10^{-19} \times V) = \frac{1}{2} \times 4 \times 1.66 \times 10^{-27} \times (5 \times 10^6)^2$$

Ex*4.* ***An α-particles of kinetic energy of 5.4 MeV is projected towards gold nucleus. Calculate the distance of closet approach. (Atomic number of gold = 79, 1 eV =*** 1.6×10^{-19} ***J)***

Sol : $K.E. = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r}$

or $5.4 \times 10^6 \times 1.6 \times 10^{-19} = 9 \times 10^9 \times \frac{(2 \times 1.6 \times 10^{-19}) \times (79 \times 1.6 \times 10^{-19})}{r}$

$\therefore$ $r = 4.21 \times 10^{-14}$ *m*

Ex.*5* ***An α-particles is projected towards the following nucleus with same kinetic energy in different experiement the distance of closet approch is maximum for***

(A) Na (Z = 11) ***(B) Ca (Z = 20)***
(C) Ag (Z = 47) ***(D) Au (Z = 79)***

Answer.(A)

Ex.*6.* ***An α-particle, a proton, a deutron and a neutron are projected towards the same nucleus with the same kinetic energy in different experiement. The distance of closet approch is minimum for***

(A) α ***(B) P*** ***(C) d*** ***(D) n***

Answer.(D)

Ex.7 An α-particle having K.E. = 7.7 MeV is scattered by gold (Z = 79) nucleus through 180°. Find distance of closest approach.

K.E. = 7.7 M eV

$= 7.7 \times 10^6 \times 1.6 \times 10^{-19}$ J

$= 1.23 \times 10^{-12}$ J

$$\frac{1}{4\pi\varepsilon_0} = 9\times10^9 \text{Nm}^2\text{C}^{-2}$$

Using we get : $\dfrac{9\times10^9\times2\times79\times(1.6\times10^{-19})^2}{1.23\times10^{-12}}$

$r_0 = 3 \times 10^{-14}$ m

From the above example it is clear that nuclear dimension cannot be greater than 3×10^{-14} m.

Ex.8. *Calculate the frequency of EMR (Electromagnetic radiation) of wave number 10^4 cm^{-1}.*

Sol : $\nu = \dfrac{c}{\lambda} = c\bar{\nu}$ *= (3 × 10^8 m/s)(10^4 cm^{-1}) = (3 × 10^{10} cm/s)(10^4 cm^{-1}) = 3 × 10^{14} Hz.*

Ex.9. *A radio station radiate the radiowaves of frequency 20kHz. What is meter band of that radio station?*

Sol : $20\text{kHz} = \dfrac{3\times10^8}{\lambda} \Rightarrow \lambda = 1.5 \times 10^4$ *m*

Ex.10. Calculate the energy per quanta of an EMR of frequency 400 MHz.

Sol : *$E = 6.626 \times 10^{-34} \times 4 \times 10^6$ J/quanta*

Ex.11. Calculate the energy per quanta of an EMR of wavelength 662.6 nm.

Sol : $E = n\dfrac{hc}{\lambda} = \dfrac{6.626\times10^{-34}\times3\times10^8}{662.6\times10^{-9}\text{m}}$ *= 3 × 10^{-19} J/quanta*

Ex.12. Calculate the wavelength (in Å) of an EMR of energy 3.1 eV/quanta.

Sol: $E = h\nu = h\dfrac{c}{\lambda} \Rightarrow E(ev) \times 1.602 \times 10^{-19} = \dfrac{1\times6.62\times10^{-34}\times3\times10^8}{\lambda(\text{Å})}$

$$\boxed{\text{E(eV)} \approx \frac{12400}{\lambda(\text{Å})} = \frac{1240}{\lambda(\text{nm})}}$$

Ex.13. In order to see an object, 10^{-19}J must be recived by our eyes. How many photons of green light must be recieved by our eyes for its visibility. (λ = 550 nm, h = 6.6 × 10^{-34} J)

Sol : $E = n\dfrac{hc}{\lambda}$

$$10^{-19} = n\times\frac{6.6\times10^{-34}\times3\times10^8}{5500\times10^{-9}}$$

$$n = \frac{5}{18} \approx 1$$

Ex.14. A bulb is rated as 110 watt. If it emits 25% of absorbed energy as red light (λ = 6626Å), how many photons are emitted out by the bulb per second.

Sol: $110\times\frac{25}{100}=n\times\frac{6.626\times10^{-34}\times3\times10^{8}}{6626\times10^{-10}}$

Ex.15. The wavelength of microwave radiation is 0.08 m. How many moles of photons is needed to increase the temperature of 400 gm water from 25° to 45°C, assuming 25% efficiency.
Specific heat capacity = 4.2 J/K-gm

Sol : $\left(\frac{nhc}{\lambda}\right)\times\frac{25}{100}=ms\Delta t$

$$n\times\frac{6.626\times10^{-34}\times3\times10^{8}}{0.08}\times\frac{25}{100}=400\times4.2\times20$$

$$\therefore\quad \text{Number of moles of photon}=\frac{n}{N_A}$$

Ex.16. A dye absorbs the radiation of 4000 Å and fluoresces the radiation of 5000 Å. If only 40% of the absorbed energy is emitted out, calculate the ratio of number of quanta emitted out and the number of quanta absorbed.

Sol: $E_a\times\frac{40}{100}=E_e$

$$n_a\times\frac{hc}{4000Å}\times\frac{40}{100}=n_e\times\frac{hc}{5000Å}$$

$$\frac{n_e}{n_a}=\frac{40}{100}\times\frac{5000}{4000}=\frac{1}{2}$$

Ex.17. The bond dissociation energy of Cl–Cl bond in chlorine gas is 240 kJ/mol. Calculate the longest wavelength of EMR needed to dissociate bond. Assume one photon may dissociate only one bond.

Sol : $\frac{240\times10^{3}}{6\times10^{23}}=\frac{1\times6.626\times10^{-34}\times3\times10^{8}}{\lambda}$

Ex.18 A near ultra violet photon of wavelength 300 nm is absorbed by a gas and then emitted as two photons. One photon is of red light with wavelength 760 nm. What would be the wave length of the second photon ?

Sol. It may noted that energy of photon which adsorbed is emitted as sum of the energy of two photons.

Energy absorbed $h\nu = \frac{hc}{\lambda}$

According to available information,

$$\frac{hc}{\lambda} = \frac{hc}{\lambda_1} + \frac{hc}{\lambda_2}; \frac{1}{\lambda} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}; \frac{1}{\lambda_2} = \left[\frac{1}{\lambda} - \frac{1}{\lambda_1}\right]$$

Now, $\lambda = 300$ nm ; $\lambda_1 = 760$ nm ; λ_2 can be calculated as :

$$\frac{1}{\lambda_2} = \left[\frac{1}{300} - \frac{1}{760}\right] = \frac{760-300}{300\times 760}(\text{nm}^{-1})$$

$$\frac{1}{\lambda_2} = \frac{460}{760\times 300}(\text{nm}^{-1})$$

or $\lambda_2 = 496\,\text{nm}$

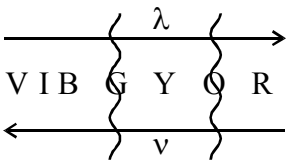
Ex.19. From a metal surface, photoelectron never comes out by orange light but comes from green light. Predict about the injection of photoelectron from the same metal by

(i) Red (ii) Blue (iii) Yellow light

Sol: *(i) Red light = No*

(ii) Blue light = Yes

(iii) Yellow light = Can't say



Ex.20. The work function of a metal is 3 eV. If EMR of 200 nm fall on the metal surface, calculate the maximum speed of photoelectron ejected.

Sol: $E = \frac{1240}{200} = 6.2\text{eV}$

$(KE)_{max} = h\nu - \phi$

$\frac{1}{2}mv^2 = (6.2-3)\text{eV}$

$\frac{1}{2}\times 9.1\times 10^{-31} v_{max}^2 = 3.2\times 1.6\times 10^{-19}$

Ex.21. When EMR of frequency 5×10^{15} Hz fall on a metal surface, the maximum kinetic energy of photoelectron is double than the photoelectron which emitts when EMR of frequency 3×10^{15} Hz fall on the same metal. The thresold frequency for the metal is

Sol: $(K.E.)_1 = h \times 5 \times 10^{15} - h\nu_0$

$(K.E.)_2 = h \times 3 \times 10^{15} - h\nu_0$

$2E_1 = E_2$

$\nu_0 = 1 \times 10^{15}$ Hz.

Ex.22 A photon of wavelength 3000 Å strikes a metal surface, the work function of the metal being 2.20 eV. Calculate (i) the energy of the photon in eV (ii) the kinetic energy of the emitted photo electron and (iii) the velocity of the photo electron.

Sol. (i) Energy of the photon

$$E = h\nu = \frac{hc}{\lambda} = \frac{\left(6.6\times10^{-34}\,Js\right)\left(3\times10^{8}\,ms^{-1}\right)}{3\times10^{-7}\,m} = 6.6 \times 10^{-19}\ J$$

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

$$\text{Therefore } E = \frac{6.6\times10^{-19}\,J}{1.6\times10^{-19}\,J/eV} = 4.125\ eV$$

(ii) Kinetic energy of the emitted photo electron

Work function = 2.20 eV

Therefore, KE = 2.475 – 2.20

= 1.925 eV = 3.08×10^{-19} J

(iii) Velocity of the photo electron

$$KE = \frac{1}{2}mv^2 = 3.08 \times 10^{-19}\ J$$

$$\text{Therefore, velocity (v)} = \sqrt{\frac{2\times3.08\times10^{-19}}{9.1\times10^{-31}}} = 8.22 \times 10^{5}\ ms^{-1}$$

4. BOHR'S ATOMIC MODEL

Bohr's model for hydrogen atom is based on the following postulates:

(i) The electron in the hydrogen atom can move around the nucleus in a circular path of fixed radius and energy. These paths are called **orbits**, stationary states or allowed energy states. These orbits are arranged concentrically around the nucleus.

(ii) The energy of an electron in the orbit does not change with time. However, the electron will move from a lower stationary state to a higher stationary state when required amount of energy is absorbed by the electron or energy is emitted when electron moves from higher stationary state to lower stationary state. The energy change does not take place in a continuous manner.

Niels Bohr
(1885-1962)

Niels Bohr, was a Danish physicst. After first world war, Bohr worked for peaceful uses of atomic energy. He was awarded the Nobel Prize in physics in 1922.

(iii) The frequency of radiation absorbed or emitted when transition occurs between two stationary states that differ in energy by ΔE, is given by :

$$\nu = \frac{\Delta E}{h} = \frac{E_2 - E_1}{h}$$

Where E_1 and E_2 are the energies of the lower and higher allowed energy states respectively. This expression is commonly known as Bohr's frequency rule.

(iv) The angular momentum of an electron in a given stationary state can be expressed as in equation

$$m_e vr = n \cdot \frac{h}{2\pi} \qquad n = 1, 2, 3$$

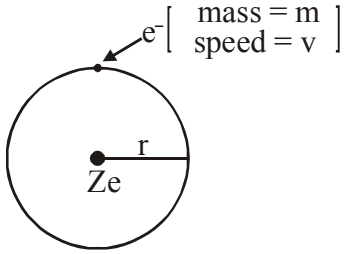
Thus an electron can move only in those orbits for which its angular momentum is integral multiple of $h/2\pi$ that is why only certain fixed orbits are allowed.

4.1 APPLICATION OF BOHR'S MODEL

When electron revolves in fixed circular orbit than electrostatic force of attraction and centrifugal force are equal.

Electrostatic force $= \frac{Kq_1q_2}{r^2} = \frac{K.Ze.e}{r^2} = \frac{KZe^2}{r^2}$

Where, constant $K = 9 \times 10^9 Nm^2/C^2$ (MKS) = 1 (CGS)



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

In balanced condition

Electrostatic force = Centrifugal force

$$\frac{KZe^2}{r^2} = \frac{mv^2}{r} \text{ or } \frac{KZe^2}{r} = mv^2 \text{ or } \frac{Ze^2}{r} = mv^2 \text{ (CGS)} \qquad \text{.....(i)}$$

4.1.1 Radius of various orbits (shell) :

According to Bohr model, $mvr = \frac{nh}{2\pi}$

$$v = \frac{nh}{2\pi mr} \qquad \textbf{.....(ii)}$$

Now putting the value of v from eq.(ii) into eq.(i)

$$\frac{KZe^2}{r} = m\left(\frac{nh}{2\pi mr}\right)^2$$

$$\frac{KZe^2}{r} = \frac{mn^2h^2}{4\pi^2m^2r^2}$$

$$r = \frac{n^2h^2}{4\pi^2mKZe^2} \quad \text{or} \quad r = \frac{n^2h^2}{4\pi^2mZe^2} \quad (\text{CGS } \because K = 1) \textbf{ .....(iii)}$$

Putting the value of π, h, m, K, & e (Constants) in the above eq .(iii)

$r = 0.529 \times 10^{-10} \times \frac{n^2}{Z}$ m $\qquad \{ Å = 10^{-10} m = 10^{-8} cm \}$

or $\boxed{r_n = 0.529 \times \frac{n^2}{Z} Å}$

This formula is only applicable for hydrogen and hydrogen like species i.e. species containing single electron.

4.1.2. Velocity of electron in Bohr orbit :

According to Bohr postulate

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

$$v = \frac{nh}{2\pi mr} = \frac{nh}{2\pi m \times n^2h^2 / 4\pi^2 mKZe^2}$$

$$v = \frac{2\pi KZe^2}{nh} \quad \text{(MKS) .....(iv)}$$

$$v = \frac{2\pi Ze^2}{nh} \quad \text{(CGS)}$$

Putting the value of π, h, K, & e (Constants) in the above eq (iv)

$$\mathbf{v = 2.18 \times 10^6 \frac{Z}{n} m/s}$$

4.1.3. Total energy of electron in Bohr orbit :

Total energy of an electron is the sum of kinetic and potential energy.

i.e. T.E. = K.E.+ P.E.

(i) Potential energy : $P.E. = -\frac{Kq_1q_2}{r} = = -\frac{KZe^2}{r} = -\frac{KZe^2}{r}$

(ii) Kinetic energy : $K.E. = \frac{1}{2}mv^2$

But $\frac{KZe^2}{r} = mv^2$ (By eq. i)

$$K.E. = \frac{KZe^2}{2r}$$

(iii) Total energy : T.E. = K.E.+ P.E.

$$T.E. = \frac{KZe^2}{2r} - \frac{KZe^2}{r} = -\frac{KZe^2}{2r}$$

Now putting the value of r from eq. (iii)

$$T.E. = -\frac{KZe^2 \times 4\pi^2 mKZe^2}{2n^2h^2} \Rightarrow -\frac{2\pi^2 m \times K^2Z^2e^4}{n^2h^2}$$

Now putting the value of π, K, e, m, h, we get :

$$T.E. = -2.18 \times 10^{-18} \times \frac{Z^2}{n^2} \text{ J / atom} = -1312 \times \frac{Z^2}{n^2} \text{ kJ/mol}$$

$$= -2.18 \times 10^{-11} \times \frac{Z^2}{n^2} \text{ erg/atom} = -313.6 \times \frac{Z^2}{n^2} \text{ Kcal/mol}$$

$$= -13.6 \times \frac{Z^2}{n^2} \text{eV/atom} \Rightarrow E_n = -\frac{13.6Z^2}{n^2} \text{eV / atom}$$

4.1.4 Some extra points :

(i) $K.E = \frac{KZe^2}{2r}$ i.e. $K.E. \propto \frac{1}{r}$ On increasing radius, K.E. decreases.

(ii) $P.E. = -\frac{KZe^2}{r}$ i.e. $P.E. \propto -\frac{1}{r}$ On increasing radius, P.E. increases.

(iii) $T.E. = -\frac{KZe^2}{2r}$ i.e. $E. \propto -\frac{1}{r}$ On increasing radius, total energy increases.

(iv) Relation between T.E., P.E. and K.E.

$P.E = -2\ KE$

$KE = -T.E.$

$P.E = 2\ T.E.$

4.1.5 Important Definations :

(i) Ionization energy :

Minimum energy required to liberate an electron from the ground state of an isolated atom is called the ionization energy.

(ii) Separation energy :

Minimum energy required to remove an electron from its excited state is called as separation energy.

(iii) Excitation energy :

Amount of energy required to shift an electron from ground state to any excited state.

Note : All these kinds of energy are always positive.

Ex.23. Calculate the radius of Ist 4 orbits of hydrogen atom

Sol: $r_1 = 0.529 \times \frac{1^2}{1} = 0.529\text{Å}$

$r_2 = 0.529 \times \frac{2^2}{1} = 2.116\text{Å} = r_1 \times 2^2$

$r_3 = 0.529 \times \frac{3^2}{1} = 4.761\text{Å} = r_1 \times 3^2$

$r_4 = 0.529 \times \frac{4^2}{1} = 8.464\text{Å}$

From this, for same Z : $r_n = r_1 \times n^2$

Ex.24 Calculate the ratio of radius of 2nd orbits of Li^{2+} atom & 3rd orbits He^+ ion.

Sol: $\frac{r_{2,Li^{2+}}}{r_{3,He^+}} = \frac{0.529 \times \frac{4}{3}}{0.529 \times \frac{9}{2}} = \frac{8}{27}$

Ex.25 Calculate the radius ratio of 3rd & 5th orbit of He^+.

Sol. $r = 0.529 \times \frac{n^2}{Z}$ Å

At. Number of He = 2

$\therefore \quad r_3 = 0.529 \times \frac{(3)^2}{2} = 0.529 \times \frac{9}{2}$

$r_5 = 0.529 \times \frac{(5)^2}{2} = 0.529 \times \frac{25}{2}$

Therefore $\frac{r_3}{r_5} = \frac{0.529 \times \frac{(3)^2}{2}}{0.529 \times \frac{(5)^2}{2}}$

$\frac{r_3}{r_5} = \frac{9}{25}$

Ex.26 Calculate the energy of Li^{+2} atom for 2nd excited state.

Sol. $E = -13.6 \times \frac{Z^2}{n^2}$

$\because$ Z = 3 and e^- exist in 2nd excited state, means e^- present in 3rd shell i.e. n = 3

$\therefore \quad E = -13.6 \times \frac{(3)^2}{(3)^2} = -13.6$ eV/atom

Ex.27 If the P.E. of an electron is – 6.8 eV in hydrogen atom then find out K.E., E of orbit where electron exist & radius of orbit.

Sol. (i). P.E. = –2K.E.

–6.8 = –2K.E.

$\frac{6.8}{2}$ = K.E. K.E. = 3.4 eV

(ii). E. = – K.E.

= – 3.4 eV

(iii). Orbit = 2nd

$\because \quad E = -13.6 \times \frac{Z^2}{n^2}$

$\therefore \quad 3.4 = -13.6 \times \frac{1^2}{n^2}$

$\Rightarrow \quad n^2 = \frac{-13.6}{-3.4} = 4$

i.e. n = 2

(iv). $r = 0.529 \times \frac{n^2}{Z}$ Å

$r = 0.529 \times \frac{(2)^2}{1}$ Å

$= 0.529 \times 4Å = 2.16$ Å

Ex.28 ***The ionization energy for the hydrogen atom is 13.6 eV then calculate the required energy in eV to excite it from the ground state to 1st excited state.***

Sol. Ionization energy = 13.6 eV

i.e. 1st energy state = – 13.6 eV

Energy of 1st excited state

i.e. 2nd orbit = –3.4 eV

so, $E_2 - E_1 = -3.4 + 13.6 = 10.2$ eV

Ex.29 *Calculate the amount of energy absorbed in the trasition n = 1 to n = 3 in Li^{2+} ion.*

Sol. *n_1 orbit $\rightleftharpoons$ n_2 orbit*

$$\Delta E = E_{n_2} - E_{n_1} = \left(-13.6\frac{z_1^2}{n_2^2}\right) - \left(-13.6\frac{z_2^2}{n_1^2}\right)$$

$$\Delta E = 13.6 z^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) eV$$

$$\Delta E = 13.6 \times 3^2 \left(\frac{1}{1^2} - \frac{1}{3^2}\right) = 108.8 eV$$

Ex.30 *Calculate the excitation energy of Be^{3+} ion in ground state.*

Sol. $\Delta E = 13.6 \times 16\left(\frac{1}{1} - \frac{1}{4}\right) = 163.2$ *eV*

Ex.31 *The ionisation energy of He^+ ion is x kJ/mole. Calculate ionisation energy of Li^{2+} ion.*

Sol. *For I.E. $\Rightarrow n = 1 \longrightarrow n = \infty$*

$$IE = 13.6 z^2 \left(\frac{1}{1^2} - \frac{1}{\infty^2}\right) = 13.6\ z^2\ eV$$

$$\frac{(I.E.)_{Li^{2+}}}{(I.E.)_{He^+}} = \frac{3^2}{2^2} \quad \Rightarrow \quad (I.E.)_{Li^{2+}} = \frac{9}{4}x \ kJ/mol$$

Ex.32 *The ionisation energy for a single electron system is 14.4 eV. Calculate the amount of energy released when electron jumps from 3rd orbits to 2nd orbit.*

Sol. $\Delta E = (IE)\left(\frac{1}{n_1^2} - \frac{1}{n^2}\right) = 14.4 \times \left(\frac{1}{4} - \frac{1}{9}\right) = 2$ *eV*

Ex.33 *Calculate the speed of an electron in the 3rd orbit of the Li^{2+} ion. Also calculate the number of revolutions per second that it makes around the nucleus.*

Sol. *Radius of 2nd orbit = $r_1 x \frac{(n)^2}{Z} = 0.529 \times \frac{(3)^2}{3} = 1.587Å$*

Velocity of electron in 2nd orbit, $v = 2.18 \times 10^6 \frac{Z}{n}$ *m/sec* $= 2.18 \times 10^6$ *m/sec*

$$\text{No. of revolutions/sec} = \frac{1}{2\pi r/v} = \frac{v}{2\pi r} = \frac{2.18\times10^6 \text{m/sec}}{2\times3.14\times1.587\times10^{-10}\text{m}}$$

$$= 2.187 \times 10^{15} \text{ rev/sec}$$

5.1 RYDBERG FORMULA

It an electron shows transition from n_2 to n_1 energy level then energy change ΔE will be.

$$\Delta E = En_2 - En_1$$

$$\Delta E = \frac{-2\pi^2 mK^2Z^2e^4}{n_2^2h^2} - \left[\frac{-2\pi^2 mK^2Z^2e^4}{n_1^2h^2}\right] = \frac{2\pi^2 mK^2Z^2e^4}{n_1^2h^2} - \frac{2\pi^2 mK^2Z^2e^4}{n_2^2h^2}$$

But $\Delta E = h\nu = \frac{hc}{\lambda}$

$$\therefore \quad \frac{hc}{\lambda} = \frac{2\pi^2 mK^2Z^2e^4}{h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$$\frac{1}{\lambda} = \frac{2\pi^2 mK^2e^4Z^2}{ch^3}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

where $\frac{2\pi^2 mK^2e^4}{ch^3}$ is a constant called Rydberg constant (R) (Assume nucleus is stationary)

So, $\bar{\nu} = \frac{1}{\lambda} = RZ^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

value of R $= 109677 \text{ cm}^{-1} = 10967700 \text{m}^{-1}$

$\simeq 109700 \text{ cm}^{-1} \simeq 10970000 \text{ m}^{-1}$

$$\frac{1}{R} = 912\text{Å}$$

Ex.34 What is the wavelength of light emitted when the electron in a hydrogen atom undergoes transition from the energy level with n = 4 to the energy level with n = 1 ?

Sol. According to Rydberg's formula, $\bar{\nu}(\text{cm}^{-1}) = 109,677\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

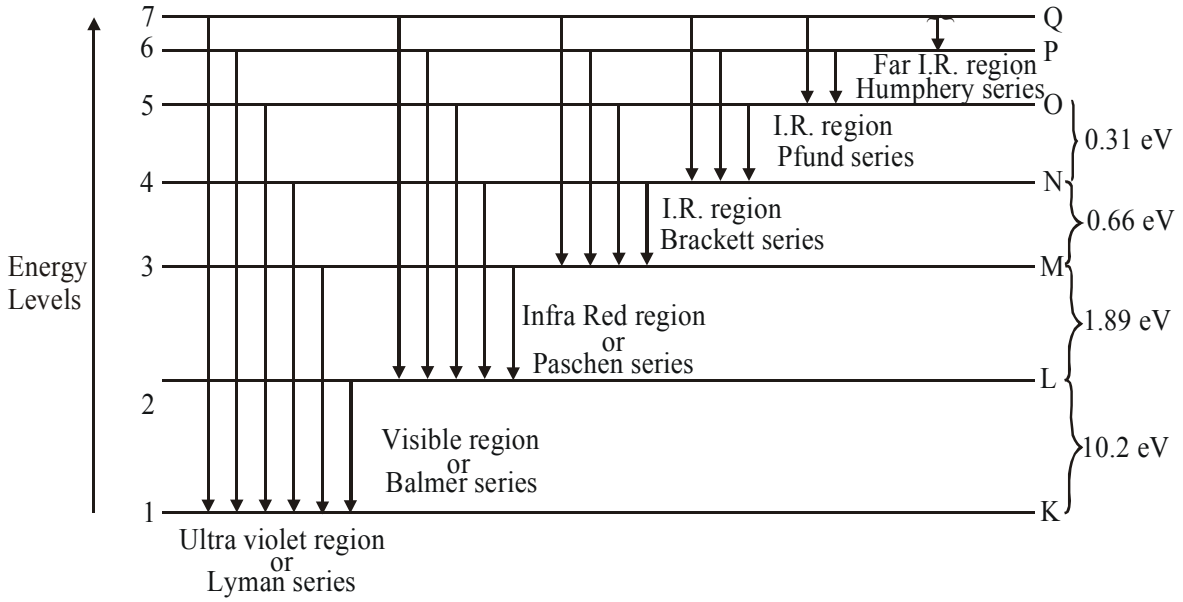
In the present case $n_2 = 4$ and $n_1 = 1$

$$\bar{\nu} = 109,677\left(\frac{1}{(1)^2} - \frac{1}{(1)^2}\right) = 109,677 \times \frac{15}{16} = 102822\text{cm}^{-1}$$

$$\lambda = \frac{1}{\bar{\nu}} = \frac{1}{102822}\text{cm} = 9.7 \times 10^{-6} \text{ cm} = 9.7 \times 10^{-6} \times 10^7 \text{ nm} \textbf{ = 97 nm.}$$

5.2 HYDROGEN LINE SPECTRUM :

When an electric excitation is applied on atomic hydrogen gas at low pressure,a bluish light is emitted. when a ray of this light is passed through a prism, a spectrum of several isolated sharp lines is obtained. The wavelength of various lines show that spectrum lines lie in visible, Ultraviolet and Infra red region. These lines are grouped into different series.



Series	Discovered by	Regions	n_2	n_1
Lyman	Lyman	U.V. region	$n_2 = 2,3,4 ...$	$n_1=1$
Balmer	Balmer	Visible region	$n_2 = 3,4,5 ...$	$n_1=2$
Paschen	Paschen	Infra red (I.R.)	$n_2 = 4,5,6 ...$	$n_1=3$
Brackett	Brackett	I.R. region	$n_2 = 5,6,7 ...$	$n_1=4$
Pfund	Pfund	I.R. region	$n_2 = 6,7,8 ...$	$n_1=5$
Humphery	Humphery	Far I.R. region	$n_2 = 7,8,9 ...$	$n_1=6$

☐ KEY POINTS :

- First line / Starting line / Initial line ($\lambda_{max.}$ and ν_{min})
- Last line / limiting line / Series limit (λ_{min} and $\nu_{max.}$)
- First line of any series = α line
  Second line of any series = β line

Third line of any series = γ line

- Total no. of emission lines between n_2 & $n_1 = \frac{(n_2 - n_1)(n_2 - n_1 + 1)}{2}$, $(n_2 > n_1)$
- For transition from any orbit 'n' to n = 1 , total no. of emission lines $= \frac{n(n-1)}{2}$

Ex.35 In a hydrogen spectrum if electron moves from 6^{th} to 2^{nd} by transition in multi steps then find out the number of lines in spectrum

Sol. *Total number of line* $= 4 + 3 + 2 + 1 + 0 = 10$

Total number of lines $= \frac{(n_2 - n_1)\left[(n_2 - n_1) + 1\right]}{2} = \frac{(6-2)(4+1)}{2} = 10$

Ex.36 In the spectrum of He^+ ion the wavelength of α line of Balamer series is x Å. What is the wavelength of α line of Paschen series.

Sol. $\frac{1}{\lambda_1} = Rz^2\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$

$$\frac{1}{\lambda_2} = Rz^2\left(\frac{1}{3^2} - \frac{1}{5^2}\right)$$

$$\frac{\lambda_2}{\lambda_1} = \frac{\frac{1}{2^2} - \frac{1}{3^2}}{\frac{1}{3^2} - \frac{1}{5^2}} \quad \Rightarrow \quad \frac{\lambda_2}{x\text{Å}} = \frac{5}{16} \times \frac{25}{4}$$

Ex.37 A sample of He^+ ions in ground state absorbs the radiation of x Å. subsequently, the sample emit radiation of 6 different wavelength. Calculate the value of x.

Sol. $\frac{1}{x} = R\left(\frac{1}{1^2} - \frac{1}{4^2}\right) \times 2^2$

$$x = \frac{16}{15} \times \frac{912}{4}\text{Å}$$

Ex.38 In a hydrogen spectrum if electron moves from 6^{th} to 2^{nd} by transition in multi steps then find out the number of lines in spectrum

Sol. Total number of line $= 4 + 3 + 2 + 1 + 0$

$= 10$

Total number of lines $= \frac{(n_2 - n_1)\left[(n_2 - n_1) + 1\right]}{2} = \frac{(6-2)(4+1)}{2} \Rightarrow \frac{4 \times 5}{2} = 10$

5.3 Limitation of the Bohr's model

(i) Bohr's theory does not explain the spectrum of multi electron atom.

(ii) Why the Angular momentum of the revolving electron is equal to $\frac{nh}{2\pi}$, has not been explained by Bohr's theory.

(iii) Bohr inter-related quantum theory of radiation and classical law of physics without any theoretical explanation.This was the biggest drawback of this model.

(iv) Bohr's theory does not explain the fine structure of spectral lines. Fine structure of the spectral line is obtained when spectrum is viewed by a spectroscope of high resolving power.

(v) Bohr's theory does not explain the splitting of spectral lines in the presence of magnetic field **(Zeeman effect)** or electric field **(Stark effect)**

5.4 Photoelectric effect

(a) Kinetic energy = = $h\nu - w = h\nu - h\nu_0$

where w = work function

ν_0 = Threshhold frequency

(b) Accelerating potential = eV = KE = $\frac{1}{2}mv^2$

(c) $\nu^{1/2} = a(z-b)$ b = screening constant

6. DUAL BEHAVIOUR OF MATTER & DE BROGLIE WAVELENGTH :

In 1923, a French physicist, ***Louis de Broglie*** suggested that, like light, matter also has dual character. It exhibits wave as well as particle nature. According to de Broglie, the wavelength λ of an electron is inversely proportional to its momentum p.

$$\lambda \propto \frac{1}{p} \quad \text{or} \quad \lambda \propto \frac{1}{mv}$$

$$\lambda = \frac{h}{p}$$

Here h = Planck's constant

p = momentum of electron

$\therefore$ Momentum (p) = Mass (m) $\times$ Velocity (v)

de Broglie'
(1892-1987)

A French physicist, studied history as an undergraduate in the early 1910,s. His interest turned to science as a result of his assignment to radio communications in world war 1. He was awarded the Nobel Prize in physics in 1929.

The above relation can be derived for a photon as follows by using Einstein's equation, Planck's quantum theory and wave theory of light.

$E = mc^2$ (Einstein's equation) .....(i)

Where E is energy, m is mass of a body and c is its velocity.

$E = h\nu = h \times \frac{c}{\lambda}$ (Planck's equation) $(\nu = \frac{c}{\lambda})$ .....(ii)

Combining (i) and (ii)

$$E = mc^2 = h \times \frac{c}{\lambda} \quad \text{or} \quad mc = \frac{h}{\lambda} \quad \text{or} \quad \lambda = \frac{h}{mc}$$

$$\boxed{\lambda = \frac{h}{mv} \text{ or } \lambda = \frac{h}{p}}$$

It is clear from the above equation that the value of λ decreases on increasing either m or v or both. The wavelength of many fast-moving objects like an aeroplane or a cricket ball, is very low because of their high mass. Thus wave nature of macroscopic objects can be neglected but for microscopic particles like electrons, protons, atoms etc. wave nature is significant & cannot be neglected.

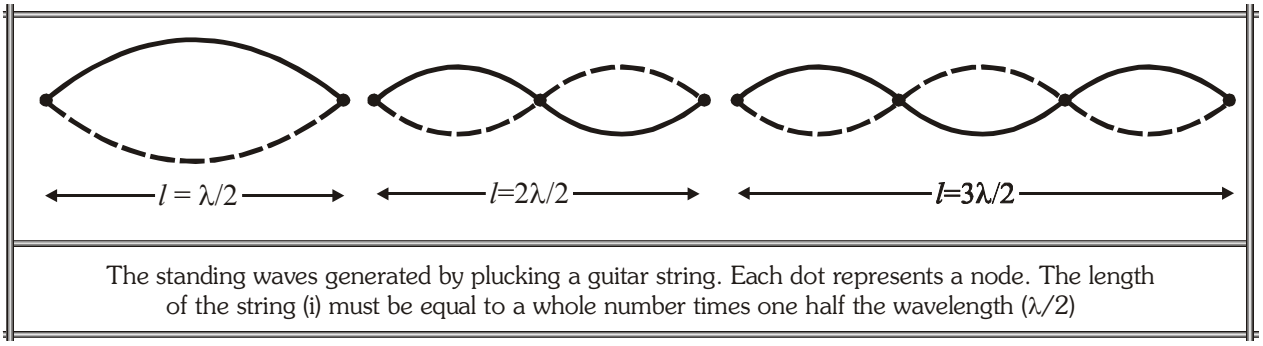
6 .1 DERIVATION OF BOHR'S ANGULAR MOMENTUM QUANTIZATION RULE :

We know that according to Bohr theory, $mvr = \frac{nh}{2\pi}$

or $2\pi r = \frac{nh}{mv}$ $(\because mv = p \text{ momentum})$

or $2\pi r = \frac{nh}{p}$ $\left(\because \frac{h}{p} = \lambda \text{ de-Broglie equation}\right)$

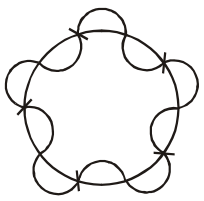
According to de Broglie, an electron bound to the nucleus behaves like a standing wave.
A standing wave – also known as a stationary wave – is a wave that remains in a constant position. Two opposing waves combine to form a standing wave. This phenomenon can occur because the medium is moving in the opposite direction to the wave, or it can arise in a stationary medium as a result of interference between two waves travelling in opposite directions.



The standing waves generated by plucking a guitar string. Each dot represents a node. The length of the string (i) must be equal to a whole number times one half the wavelength (λ/2)

For a circular standing wave to persist, a whole number of wavelength must fit into the circumference of the circle (2π).
And if n number of waves of λ wavelength are present in this circle total circumference will be nλ.

$2\pi r = n\lambda$



n = 5
∴ **Waves made = 5**

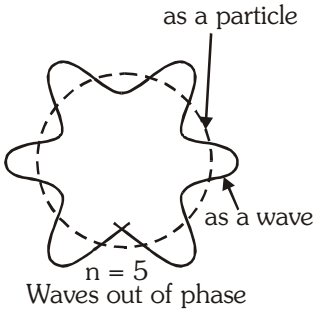
n = Number of wave made by electron in one complete revolution.

According to de Broglie

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

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

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



Waves out of phase

Therefore in $2\pi r = n\lambda$ n = Number of shell

i.e., 2^{nd} shell $2\pi r = 2\lambda$

3^{rd} shell $2\pi r = 3\lambda$

Electron in n^{th} orbit of any unielectron system can create 'n' waves in one complete revolution.

Ex.39 Calculate the de Broglie wavelength of a ball of mass 0.1 kg moving with a speed of 30 ms^{-1}.

Sol. $\lambda = \frac{h}{mv} = \frac{6.6\times10^{-34}}{0.1\times30} = 2.2 \times 10^{-34}\ m$

This is apparent that this wavelength is too small for ordinary observation.

Although the de Broglie equation is applicable to all material objects but it has significance only in case of microscopic particles.

Ex.40 What should be the mass of the sodium photon if its wavelength is 5894 Å, the velocity of light is 3×10^8 metre/second and the value of h is 6.652×10^{-34} kg m^2/sec.?

(A) 3.746×10^{-26} ***(B) 3.746×10^{-30}***

(C) 3.746×10^{-34} ***(D) 3.746×10^{-36}***

Sol. $\lambda = \frac{h}{m\times c} \Rightarrow m = \frac{h}{c\lambda}$

($\because \lambda = 5894Å = 5894 \times 10^{-10}\ m$)

$$m = \frac{6.652\times10^{-34}}{3\times10^{-8}\times5894\times10^{-10}} \quad or \quad \frac{6.652}{17682}\times10^{-32}$$

$= 0.0003746 \times 10^{-32} = 3.746 \times 10^{-36}\ kg$

Ex.41 Calculate the de-Broglie wavelength when e^- is accelerated by the following voltage.

(i) 750 V ***(ii) 300 volt***

Sol. *(i)* $\lambda = \sqrt{\frac{150}{V}}Å = \sqrt{\frac{150}{750}}Å = \frac{1}{\sqrt{5}}Å$ *(ii)* $\lambda = \sqrt{\frac{150}{300}}Å = \frac{1}{\sqrt{2}}Å$

Ex.42 *Find de-Broglie wavelength of electron with KE = 9.6×10^{-19} J.*

Sol. $KE = \frac{9.6\times10^{-19}}{1.6\times10^{-19}}eV = 6\,eV$

$$\lambda = \sqrt{\frac{150}{6}}Å = 5\,Å$$

KE of 6 eV means e^- is accelerated by 6 volt.

Ex.43 *Calculate the ratio of de-Broglie wavelength of electron and α-particle.*

(i) Moving at same speed

(ii) Moving at same momentum

(iii) Having same K.E.

(iv) Accelerated from rest through the same P.D.

Sol. *(i)* $\lambda = \frac{n}{mv}$

$$\lambda \propto \frac{1}{m}$$

$$\frac{\lambda_{electron}}{\lambda_\alpha} = \frac{m_\alpha}{m_e} = \frac{4\times1836}{1}$$

(ii) $\frac{\lambda_{electron}}{\lambda_\alpha} = \frac{1}{1}$

(iii) $\frac{h}{\sqrt{2mE}}$

$$\lambda = \frac{h}{\sqrt{2mE}} = \frac{\lambda_e}{\lambda_\alpha} = \sqrt{\frac{m_\alpha}{m_e}} = \sqrt{\frac{1836\times4}{1}}$$

(iv) $\lambda = \frac{h}{\sqrt{2mqV}} = \frac{\lambda_e}{\lambda_\alpha} = \sqrt{\frac{(mq)_\alpha}{(mq)_e}} = \sqrt{\frac{4\times2}{1/1836\times1}}$

Ex.44 ***In Li^{2+} ion electron jumps from 2nd to 1st orbit. If the emitted radiation is absorbed by H atom. Calculate the de-Broglie wavelength of the ejected electron.***

Sol. $\Delta E = 13.6\times9\left(1-\frac{1}{4}\right) = 91.8eV$

Excess energy = 91.8 – 13.6 = 78.2 eV

$$\lambda = \sqrt{\frac{150}{78.2}}\text{Å} = 1.38\text{Å}$$

Ex.45 ***Photoelectrons are liberated by ultra violet light of wavelength 2000 Å from a metallic surface for which the photoelectric threshold is 4000 Å. Calculate the de-Broglie wavelength of electrons emitted with maximum kinetic energy.***

Solution : *K.E. = Quantum Energy – Threshold energy*

$$= \frac{6.626\times10^{-34}\times3\times10^8}{2000\times10^{-10}} - \frac{6.626\times10^{-34}\times3\times10^8}{4000\times10^{-10}}$$

$$= \frac{6.626\times10^{-34}\times3\times10^8}{10^{-10}}\left(\frac{1}{2000}-\frac{1}{4000}\right) = 4.969\times10^{-19}\ \text{Joule.}$$

$\frac{1}{2}mv^2 = 4.969 \times 10^{-19} \Rightarrow m^2v^2 = 2 \times 4.969 \times 10^{-19} \times 9.1 \times 10^{-31}$

$mv = 9.51 \times 10^{-25} \Rightarrow \lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}}{9.51 \times 10^{-25}} = 0.696 \times 10^{-9}\ m$

Ex.46 Calculate the de-Broglie wavelength when proton is accelerated by the 750 V.

Sol. (i) $\lambda = \sqrt{\frac{150}{V \times 1836}}\text{Å} = \sqrt{\frac{150}{750 \times 1836}}\text{Å}$

6.2 Justification of dual nature of electrons :

I. Particle character :

(a) If an e^- strikes a screen coated with ZnS , it produces a spot of light called scintillation, On e^- produces only one scintillation point which means e^- are localised not spread out like wave : Photoelectric effect also proves its particle nature.

(b) Electron possess definite mass, momentum & KE proving their particle nature.

II. Wave character :

- It was confirmed by phenomenon of diffraction, interference, reflection.
- Davisson and Germer showed that when high speed e^- strike Ni crystal a diffraction pattern (having number of rings) is obtained like X-rays of electromagnetic spectrum.

7 HEISENBERG UNCERTAINTY PRINCIPLE :

Bohr's theory considers an electron as a material particle. Its position and momentum can be determined with accuracy. But, when an electron is considered in the form of wave as suggested by de-Broglie, it is not possible to ascertain simultaneously the exact position and velocity of the electron more precisely at a given instant since the wave is extending throughout a region of space.

In ***1927, Werner Heisenberg*** presented a principle known as Heisenberg uncertainty principle which states as : ***"It is impossible to measure simultaneously the exact position and exact momentum of a body as small as an electron".***

The uncertainty of measurement of position, Δx, and the uncertainty of momentum Δp or $m\Delta v$, are related by Heisenberg's relationship as : ($p = mv$, $\Delta p = m\Delta v$)

$$\Delta x \,.\, \Delta p \geq \frac{h}{4\pi} \quad \text{or} \quad \Delta x \,.\, m\Delta v \geq \frac{h}{4\pi}$$

or $\mathbf{\Delta x.\Delta v \geq \frac{h}{4\pi m}}$

where h is Planck's constant.

$\Delta x\ \Delta v$ = uncertainty product

For an electron of mass m (9.10×10^{-28} g), the product of uncertainty is quite large.

$$\Delta x\ .\ \Delta v\ \geq \frac{6.624\times10^{-27}}{4\pi m} \geq \frac{6.624\times10^{-27}}{4\times3.14\times9.10\times10^{-28}}$$

$$= 0.57 \text{ erg sec per gram approximately}$$

When, $\Delta x = 0$, $\Delta v = \infty$ and vice-versa.

In the case of bigger particles (having considerable mass), the value of uncertainty product is negligible. If the position is known quite accurately, i.e., Δx is very small, Δv becomes large and vice-versa.

Ex.47 ***A golf ball has a mass of 40 g and a speed of 45 m/s. If the speed can be measured within accuracy of 2 % , calculate the uncertainty in the position.***

Sol. Mass of the ball $= 40 \text{ g} = 40 \times 10^{-3}$ kg

The uncertainty in the speed,

$$\Delta v = 45 \times \frac{2}{100} = 0.9\,\text{ms}^{-1}$$

$$\Delta x = \frac{h}{4\pi m\,\Delta v} = \frac{6.626\times10^{-34}\,\text{Js}}{4\times3.14\times(40\times10^{-3}\,\text{kg})(0.9\text{ms}^{-1})} = 1.46 \times 10^{-33} \text{ m.}$$

Ex.48 Calculate the uncertainty in the velocity of a cricket ball of mass 150 g, if the uncertainty in its position in of the order of 1 Å.

($h = 6.626 \times 10^{-34}$ kg m^2 s^{-1})

Sol. Mass of ball ,

$m = 150 \text{ g} = 150 \times 10^{-3} \text{ kg} = 0.150$ kg

Uncertainty in position, $\Delta x = 1$ Å $= 10^{-10}$ m

$$\Delta x \times m\Delta v = \frac{h}{4\pi}$$

$$\Delta v = \frac{h}{4\pi\times\Delta x\times m}$$

$$= \frac{6.626\times10^{-34}\,\text{kg}\,\text{m}^2\,\text{s}^{-1}}{4\times3.14\times10^{-10}\,\text{m}\times0.150\,\text{kg}}$$

$$= 3.52 \times 10^{-24} \text{ m s}^{-1}.$$

8 QUANTUM MECHANICAL MODEL OF ATOM

Classical mechanics, based on Newton's laws of motion, successfully describes the motion of all macroscopic objects such as a falling stone, orbiting planets etc., which have essentially a particle-like behaviour as shown in the previous section. However it fails when applied to microscopic objects like electrons, atoms, molecules etc. This is mainly because of the fact that classical mechanics ignores the concept of dual behaviour of matter especially for sub-atomic particles and the uncertainty principle. The branch of science that takes into account this dual behaviour of matter is called **quantum mechanics.**

Quantum mechanics is a theoretical science that deals with the study of the motions of the microscopic objects that have both observable wave like and particle like properties. It specifies the laws of motion that these objects obey. When quantum mechanics is applied to macroscopic objects (for which wave like properties are insignificant) the results are the same as those from the classical mechanics.

Quantum mechanics was developed independently in 1926 by Werner Heisenberg and Erwin Schrodinger. Here, however, we shall be discussing the quantum mechanics which is based on the ideas of wave motion. The fundamental equation of quantum mechanics was developed by Schrodinger and it won him the Nobel Prize in Physics in 1933. This equation which incorporates wave-particle duality of matter as proposed by de Broglie is quite complex and knowledge of higher mathematics is needed to solve it. You will learn its solutions for different systems in higher classes.

For a system (such as an atom or a molecule whose energy does not change with time) the Schrodinger equation is written as

$$\hat{H}\psi = E\psi$$

$\hat{H}$ is a mathematical operator called Hamiltonian. Schrodinger gave a recipe of constructing this operator from the expression for the total energy of the system. The total energy of the system takes into account the kinetic energies of all the sub-atomic particles (electrons, nuclei), attractive potential between the electrons and nuclei and repulsive potential among the electrons and nuclei individually. Solution of this equation gives E and ψ.

8.1 *Hydrogen Atom and the Schrodinger Equation*

When Schrodinger equation is solved for hydrogen atom, the solution gives the possible energy levels the electron can occupy and the corresponding wave function(s) (ψ) of the electron associated with each energy level. These quantized energy states and corresponding wave functions which are characterized by a set of three quantum numbers (**principal quantum number *n*, azimuthal quantum number *l* and magnetic quantum number** m_l) arise as a natural consequence in the solution of the Schrodinger equation. When an electron is in any energy state, the wave function corresponding to that energy state contains all information about the electron.

Erwin Schrodinger (1887-1961)

Erwin Schrodinger, an Austrian physicist received his Ph.D. in theoretical physics from the University of Vienna in 1910. In 1927 Schrodinger succeeded Max Planck at the University of Berlin at Planck's request. In 1933, Schrodinger left Berlin because of his opposition to Hitler and Nazi policies and returned to Austria in 1936. After the invasion of Austria by Germany, Schrodinger was forcibly removed from his professorship. He then moved to Dublin, Ireland where he remained for seventeen years. Schrodinger shared the Nobel Prize for Physics with P.A.M. Dirac in 1933.

The wave function is a mathematical function whose value depends upon the coordinates of the electron in the atom and does not carry any physical meaning. Such wave functions of hydrogen or hydrogen like species with one electron are called **atomic orbitals**.

Such wave functions pertaining to one-electron species are called one-electron systems. The probability of finding an electron at a point within an atom is proportional to the $|\psi|^2$ at that point. The quantum mechanical results of the hydrogen atom successfully predict all aspects of the hydrogen atom spectrum including some phenomena that could not be explained by the Bohr model.

Application of Schrodinger equation to multi-electron atoms presents a difficulty: the Schrodinger equation cannot be solved exactly for a multi-electron atom. This difficulty can be overcome by using approximate methods. Such calculations with the aid of modern computers show that orbitals in atoms other than hydrogen do not differ in any radical way from the hydrogen orbitals discussed above. The principal difference lies in the consequence of increased nuclear charge. Because of this all the orbitals are somewhat contracted. Further, as you shall see later , unlike orbitals of hydrogen or hydrogen like species, whose energies depend only on the quantum number n, the energies of the orbitals in multi-electron atoms depend on quantum numbers *n* and *l*.

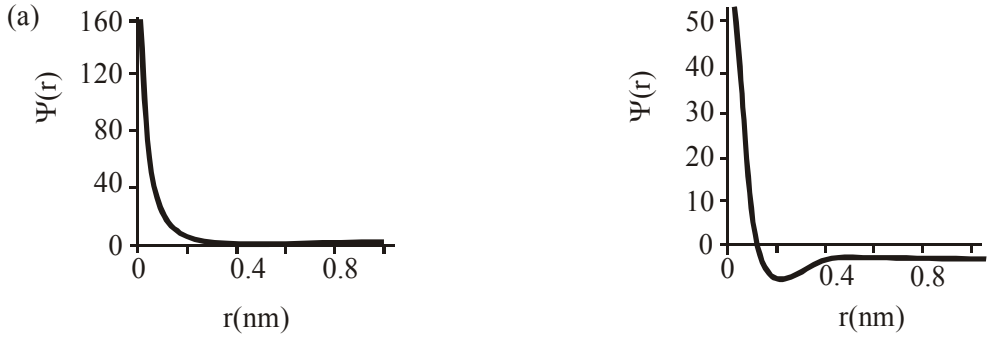
8.2 Important Features of the Quantum Mechanical Model of Atom–

Quantum mechanical model of atom is the picture of the structure of the atom, which emerges from the application of the Schrodinger equation to atoms. The following are the important features of the quantummechanical model of atom:

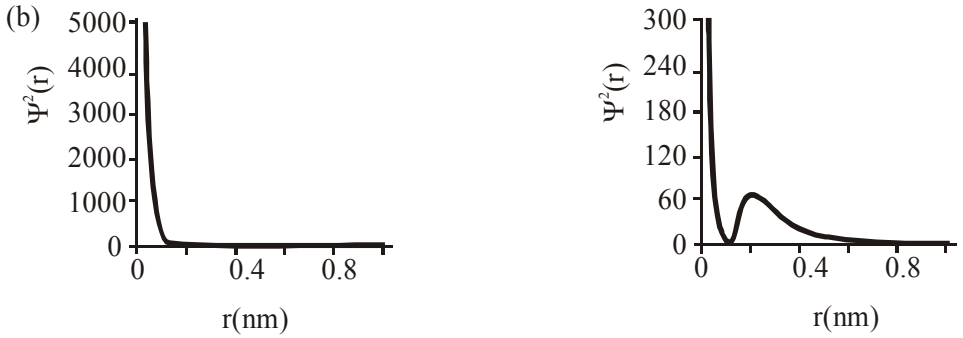
1. The energy of electrons in atoms is quantized (i.e., can only have certain specific values), for example when electrons are bound to the nucleus in atoms.
2. The existence of quantized electronic energy levels is a direct result of the wave like properties of electrons and are allowed solutions of Schrodinger wave equation.
3. Both the exact position and exact velocity of an electron in an atom cannot be determined simultaneously (Heisenberg uncertainty principle). The path of an electron in an atom therefore, can never be determined or known accurately. That is why, as you shall see later on, one talks of only probability of finding the electron at different points in an atom.
4. **An atomic orbital is the wave function ψ for an electron in an atom.** Whenever an electron is described by a wave function, we say that the electron occupies that orbital. Since many such wave functions are possible for an electron, there are many atomic orbitals in an atom. These "one electron orbital wave functions" or orbitals form the basis of the electronic structure of atoms. In each orbital, the electron has a definite energy. An orbital cannot contain more than two electrons. In a multi-electron atom, the electrons are filled in various orbitals in the order of increasing energy. For each electron of a multi-electron atom, there shall, therefore, be an orbital wave function characteristic of the orbital it occupies. All the information about the electron in an atom is stored in its orbital wave function ψ and quantum mechanics makes it possible to extract this information out of ψ.
5. The probability of finding an electron at a point within an atom is proportional to the square of the orbital wave function i.e., $|\psi|^2$ at that point. $|\psi|^2$ is known as **probability density** and is always positive. **From the value of $|\psi|^2$ at different points within an atom, it is possible to predict the region around the nucleus where electron will most probably be found.**

8.3 Shapes of Atomic Orbitals

The orbital wave function or ψ for an electron in an atom has no physical meaning. It is simply a mathematical function of the coordinates of the electron. However, for different orbitals the plots of corresponding wave functions as a function of r (the distance from the nucleus) are different. Such plots for 1s (n = 1, l = 0) and 2s (n = 2, l = 0) orbitals are

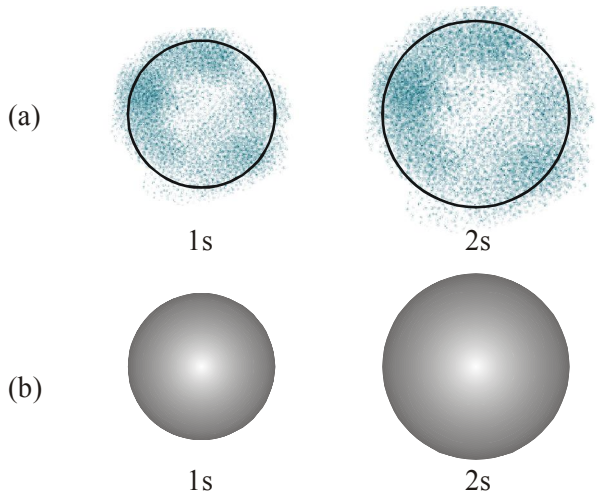


According to the German physicist, Max Born, the square of the wave function (i.e., ψ^2) at a point gives the probability density of the electron at that point. The variation of ψ^2 as a function of r for 1s and 2s orbitals is given in fig. Here again, you may note that the curves for 1s and 2s orbitals are different.



It may be noted that for 1s orbital the probability density is maximum at the nucleus and it decreases sharply as we move away from it. On the other hand, for 2s orbital the probability density first decreases sharply to zero and again starts increasing. After reaching a small maxima it decreases again and approaches zero as the value of r increases further. The region where this probability density function reduces to zero is called **nodal surfaces** or simply **nodes**. In general, it has been found that ns-orbital has (n – 1) nodes, that is, number of nodes increases with increase of principal quantum number n. In other words, number of nodes for 2s orbital is one, two for 3s and so on.

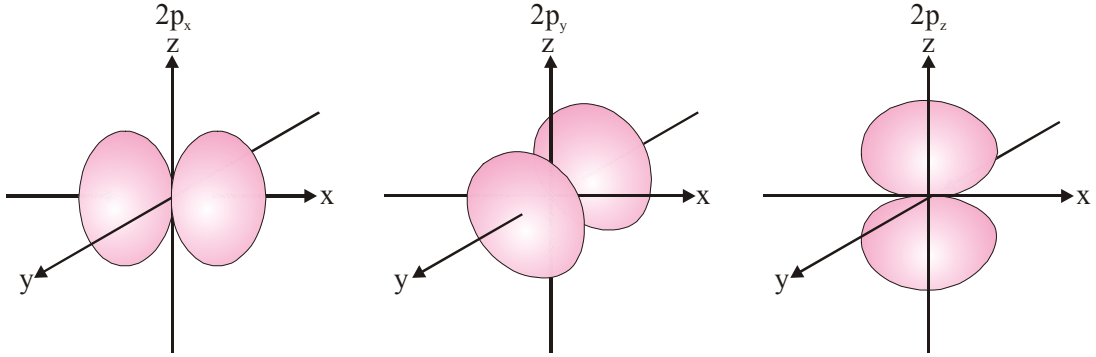
These probability density variation can be visualised in terms of charge cloud diagrams. In these diagrams, the density of the dots in a region represents electron probability density in that region.



(a) Probability density plots of 1s and 2s atomic orbitals. The density of the dots represents the probability density of finding the electron in that region. (b) Boundary surface diagram for 1s and 2s orbitals.

Boundary surface diagrams of constant probability density for different orbitals give a fairly good representation of the shapes of the orbitals. In this representation, a boundary surface or contour surface is drawn in space for an orbital on which the value of probability density $|\psi|^2$ is constant. In principle many such boundary surfaces may be possible. However, for a given orbital, only that boundary surface diagram of constant probability density is taken to be good representation of the shape of the orbital which encloses a region or volume in which the probability of finding the electron is very high, say, 90%. The boundary surface diagram for 1s and 2s orbitals are given in fig. One may ask a question : Why do we not draw a boundary surface diagram, which bounds a region in which the probability of finding the electron is, 100 %? The answer to this question is that the probability density $|\psi|^2$ has always some value, howsoever small it may be, at any finite distance from the nucleus. It is therefore, not possible to draw a boundary surface diagram of a rigid size in which the probability of finding the electron is 100%. Boundary surface diagram for a s orbital is actually a sphere centred on the nucleus. In two dimensions, this sphere looks like a circle. It encloses a region in which probability of finding the electron is about 90%.

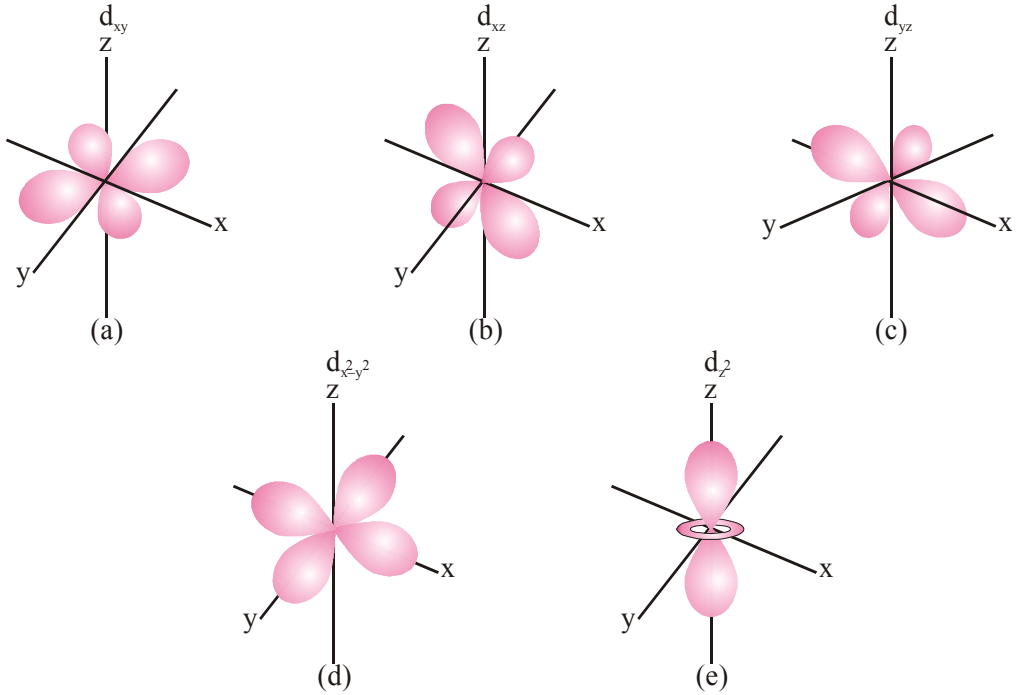
Thus we see that 1s and 2s orbitals are spherical in shape. In reality all the s-orbitals are spherically symmetric, that is, the probability of finding the electron at a given distance is equal in all the directions. It is also observed that the size of the s orbital increases with increase in n, that is, 4s > 3s > 2s > 1s and the electron is located further away from the nucleus as the principal quantum number increases. Boundary surface diagrams for three 2p orbitals (l = 1) are



Boundary surface diagrams of the three 2p orbitals.

In these diagrams, the nucleus is at the origin. Here, unlike s-orbitals, the boundary surface diagrams are not spherical. Instead each p orbital consists of two sections called lobes that are on either side of the plane that passes through the nucleus. The probability density function is zero on the plane where the two lobes touch each other. The size, shape and energy of the three orbitals are identical. They differ however, in the way the lobes are oriented. Since the lobes may be considered to lie along the x, y or z axis, they are given the designations $2p_x$, $2p_y$, and $2p_z$. It should be understood, however, that there is no simple relation between the values of m_l (.1, 0 and +1) and the x, y and z directions. For our purpose, it is sufficient to remember that, because there are three possible values of m_l, there are, therefore, three p orbitals whose axes are mutually perpendicular. Like s orbitals, p orbitals increase in size and energy with increase in the principal quantum number and hence the order of the energy and size of various p orbitals is 4p > 3p > 2p. Further, like s orbitals, the probability density functions for p-orbital also pass through value zero, besides at zero and infinite distance, as the distance from the nucleus increases. The number of nodes are given by the n – 2, that is number of radial node is 1 for 3p orbital, two for 4p orbital and so on.

For $l = 2$, the orbital is known as d-orbital and the minimum value of principal quantum number (n) has to be 3. as the value of l cannot be greater than n – 1. There are five m_l values –2, –1, 0, +1 and +2) for $l = 2$ and thus there are five d orbitals. The boundary surface diagram of d orbitals are



Boundary surface diagrams of the five 3d orbitals.

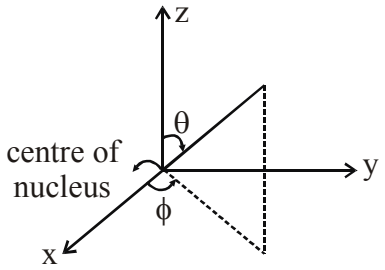
The five d-orbitals are designated as d_{xy}, d_{yz}, dxz, $d_{x^2-y^2}$ and d_{z^2}. The shapes of the first four d-orbitals are similar to each other, where as that of the fifth one, d_{z^2}, is different from others, but all five 3d orbitals are equivalent in energy. The d orbitals for which n is greater than 3 (4d, 5d...) also have shapes similar to 3d orbital, but differ in energy and size.

Besides the radial nodes (i.e., probability density function is zero), the probability density functions for the np and nd orbitals are zero at the plane (s), passing through the nucleus (origin). For example, in case of p_z orbital, xy-plane is a nodal plane, in case of d_{xy} orbital, there are two nodal planes passing

through the origin and bisecting the xy plane containing z-axis. These are called **angular nodes** and number of angular nodes are given by '*l*', i.e., one angular node for p orbitals, two angular nodes for 'd' orbitals and so on.

The total number of nodes are given by (n–1), i.e., sum of l angular nodes and (n – l – 1) radial nodes.

8.4 SOLUTION OF SCHRODINGER EQUATION :



Spherical coordinate system

The solution in spherical coordinates may be represented as :

$\psi = R(r).\Theta(\theta).\Phi(\phi)$

R(r) : Radial function depends on n and l

$\Theta(\theta).\Phi(\phi)$: Angular function depends on l and m.

8.4.1 Radical part of solution :

1s $(n = 1, \ell = 0)$: $R_{1s}(r) = 2\cdot\left(\frac{Z}{a_0}\right)^{3/2}\cdot e^{-\sigma/2}$

where $\sigma = \frac{2Zr}{na_0}$ $\quad a_0 = I^{st}$ Bohr's radius = 0.529Å

2s $(n = 2, \ell = 0)$: $R_{2s}(r) = \frac{1}{2\sqrt{2}}\cdot\left(\frac{Z}{a_0}\right)^{3/2}\cdot(2-\sigma)e^{-\sigma/2}$

2p $(n = 2, \ell = 1)$: $R_{2p}(r) = \frac{1}{2\sqrt{6}}\cdot\left(\frac{Z}{a_0}\right)^{3/2}\cdot\sigma\cdot e^{-\sigma/2}$

3s $(n = 3, \ell = 0)$: $R_{3s}(r) = \frac{1}{9\sqrt{3}}\cdot\left(\frac{Z}{a_0}\right)^{3/2}\cdot(6-6\sigma+\sigma^2)e^{-\sigma/2}$

3p $(n = 3, \ell = 1)$: $R_{3p}(r) = \frac{1}{9\sqrt{6}}\cdot\left(\frac{Z}{a_0}\right)^{3/2}\cdot\sigma(4-\sigma)e^{-\sigma/2}$

3d $(n = 3, \ell = 2)$: $R_{3d}(r) = \frac{1}{9\sqrt{30}}\cdot\left(\frac{Z}{a_0}\right)^{3/2}\cdot\sigma^2\cdot e^{-\sigma/2}$

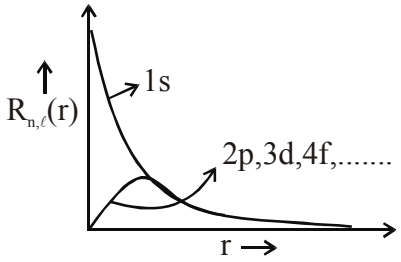
General form :

$R_{n\ell}(r) = K \cdot e^{-\sigma/2} \cdot \sigma^{\ell}$ **(Polynomial of order n – ℓ – 1)**

8.4.2 Graph of radial function [R(r) or Ψ(r)] :

Only the graph of s-orbital does not start from origin.

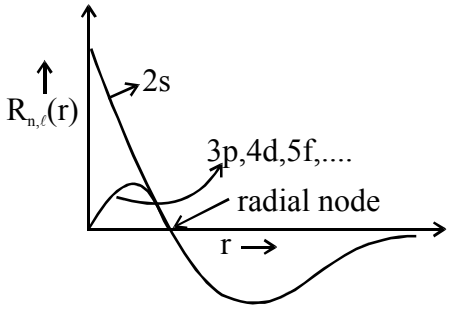
(i)



n – ℓ – 1 = 0

1s, 2p, 3d, 4f .....orbitals

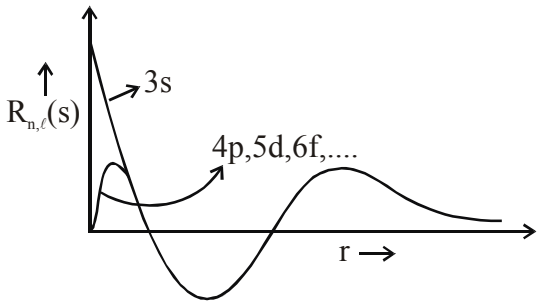
(ii)



n – ℓ – 1 = 1

2s, 3p, 4d, 5f .....orbitals

(iii)

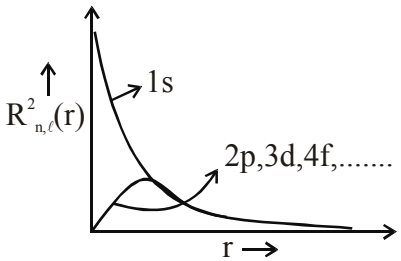


n – ℓ – 1 = 2

3s, 5p, 5d, 6f ..... orbitals

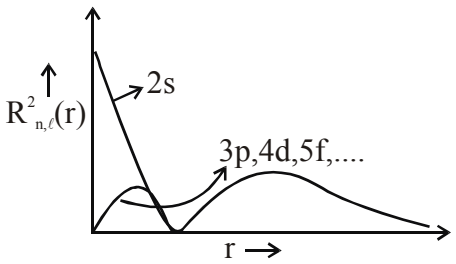
8.4.3 GRAPH OF RADIAL PROBABLITY DENSITY FUNCTION [R^2(r) or ψ^2(r)] :

(i)

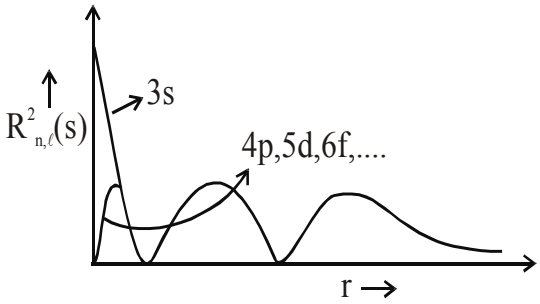


n – ℓ – 1 = 0, (1s, 2p, 3d, 4f .....orbitals)

(ii)



n – ℓ – 1 = 1 (2s, 3p, 4d, 5f .....orbitals)

(iii) 

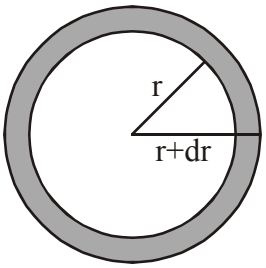
$n - \ell - 1 = 2$ (3s, 5p, 5d, 6f ..... orbitals)

8.4.3 RADIAL PROBABILITY DISTRIBUTION FUNCTION (RPDF), $4\pi r^2\psi^2(r)$

It is often useful to know the likelihood of finding the electron in an orbital at any given distance away from the nucleus. This enables us to say at what distance from the nucleus the electron is most likely to be found, and also how tightly or loosely the electron is bound in a particular atom. This is expressed by the radial probability distribution function, $4\pi r^2\psi^2(r)$.

Radial distribution function is the measure of the probability of finding the electron in a spherical shell between thickness r and (r + dr) from the nucleus, irrespective of the direction.

❖ **Volume of radial shell :**



$$dV = \begin{bmatrix}\text{Volume of sphere}\\ \text{with radius}(r+dr)\end{bmatrix} - \begin{bmatrix}\text{Volume of sphere}\\ \text{with radius } r\end{bmatrix}$$

$$= \frac{4}{3}\pi(r+dr)^3 - \frac{4}{3}\pi r^3$$

$$= \frac{4}{3}\pi(r^3 + 3r^2dr + 3rdr^2 + dr^3) - \frac{4}{3}\pi r^3 = \frac{4}{3}\pi[r^3 + 3r^2dr - r^3]$$

(As dr represents an extremely small thickness, the higher powers of dr such as dr^2 and dr^3 may be neglected.)

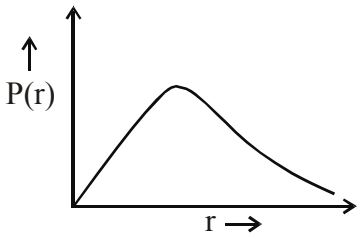
$\therefore$ Volume of shell, $dV = \frac{4}{3}(\pi \times 3r^2dr) = 4\pi r^2dr$

Now, radial probability density, $R^2(r) = \frac{P}{dV}$

$\therefore$ Probability of finding electron in the volume element,

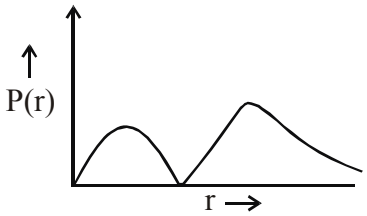
$P = R^2(r).\ dV = R^2(r).4\pi r^2.dr$

Now radial probability distribution function , $P(r) = \frac{P}{dr} = 4\pi r^2.R^2(r)$

(i) 

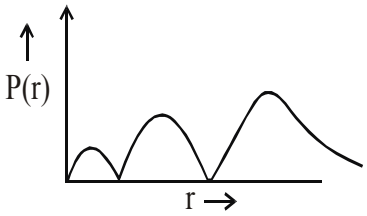
$n - \ell - 1 = 0$

1s, 2p, 3d, 4f .....orbitals

(ii) 

$n - \ell - 1 = 1$

2s, 3p, 4d, 5f .....orbitals

(iii) 

$n - \ell - 1 = 2$

3s, 5p, 5d, 6f ..... orbitals

❖ **Chracteristics of radial distribution function :**

(i) The number of maxima in radial distribution function plot are $(n - \ell)$.

(ii) The maximum probability of finding the electron, for the ground state hydrogen atom (1s) is found to be at a_0 (first Bohr radius).

(iii) For 2s, 3s, 3p orbitals , the number of maxima is more than one, indicating that there is maximum probability of finding the electron at the distance corresponding to the highest value of peak.

However, there is lesser probability of finding the electron at the other peaks. It shows that in a certain state, the electron spends some portion of its time very close to the nucleus.

8.5 ANGULAR PART OF SOLUTION :

(1) s-orbital :

$\ell = 0, m = 0$ $\qquad \Theta(\theta) \ . \ \Phi(\phi) = \sqrt{\frac{1}{4\pi}}$

As the probability of finding electron is not depending on angle (direction) then it must be same. In all direction and hence the shape of s-orbital is sphere.

(2) p-orbital :

p_x -orbital : $\ell = 1, m = +1$ $\qquad \Theta(\theta) \ . \ \Phi(\phi) = \sqrt{\frac{3}{4\pi}} \cdot \sin\theta\cos\phi$

p_y -orbital : $\ell = 1, m = -1$ $\quad \Theta(\theta) \ . \ \Phi(\phi) = \sqrt{\frac{3}{4\pi}} \cdot \sin\theta\cos\phi$

p_z -orbital : $\ell = 1, m = 0$ $\quad \Theta(\theta) \ . \ \Phi(\phi) = \sqrt{\frac{3}{4\pi}} \cdot \cos\theta$

(3) d-orbital :

d_{z^2} -orbital : $\ell = 2, m = 0$ $\quad \Theta(\theta) \ . \ \Phi(\phi) = \sqrt{\frac{5}{16\pi}}(3\cos^2\theta - 1)$

$d_{x^2-y^2}$ -orbital : $\ell = 2, m = -2$ $\quad \Theta(\theta) \ . \ \Phi(\phi) = \sqrt{\frac{15}{4\pi}} \cdot \sin^2\theta\cos 2\phi$

d_{xy} -orbital : $\ell = 2, m = +2$ $\quad \Theta(\theta) \ . \ \Phi(\phi) = \sqrt{\frac{15}{4\pi}} \cdot \sin^2\theta\sin 2\phi$

d_{xz} -orbital : $\ell = 2, m = +1$ $\quad \Theta(\theta) \ . \ \Phi(\phi) = \sqrt{\frac{15}{4\pi}} \cdot \sin\theta\cos\theta\sin 2\phi$

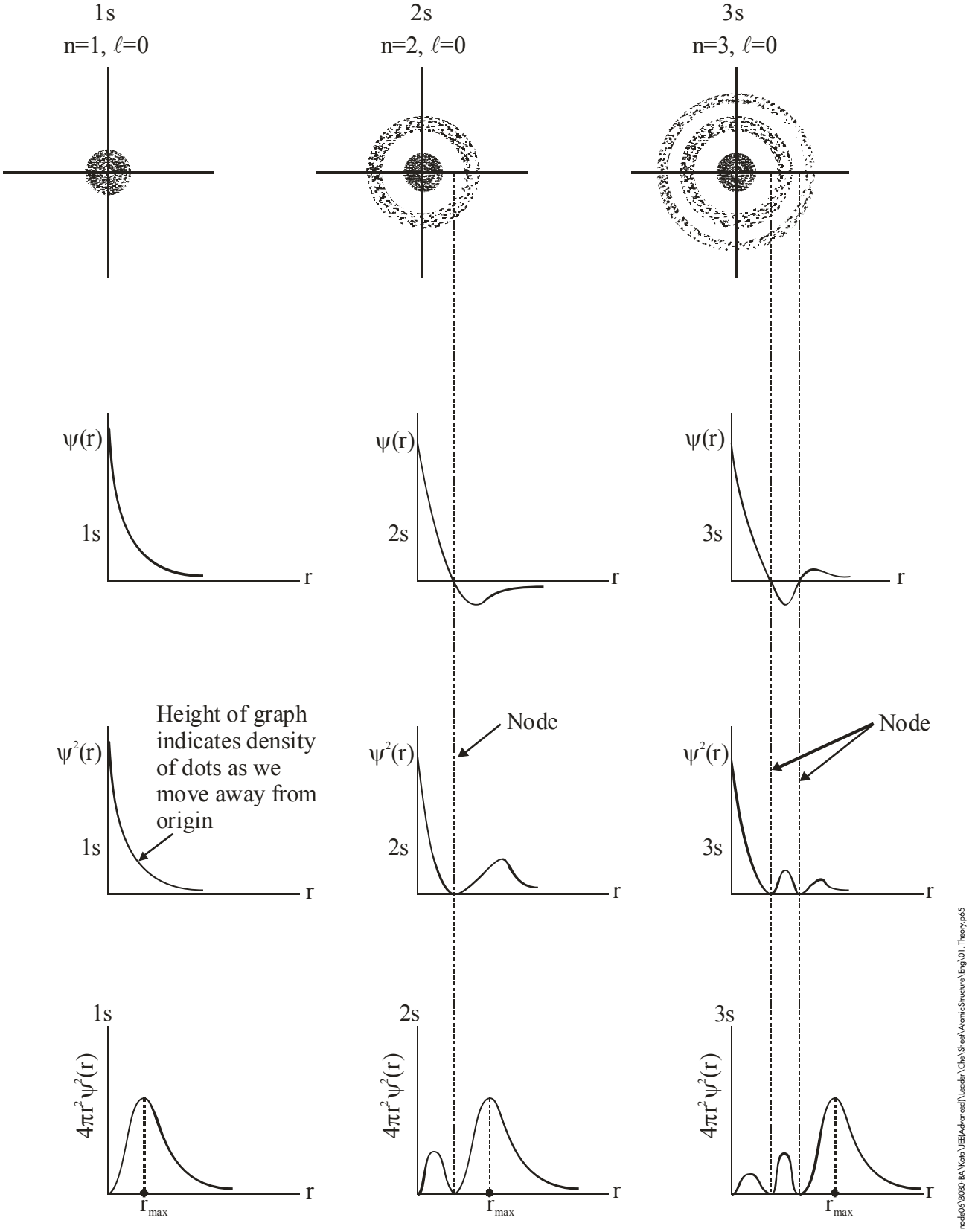
d_{yz} -orbital : $\ell = 2, m = +1$ $\quad \Theta(\theta) \ . \ \Phi(\phi) = \sqrt{\frac{15}{4\pi}} \cdot \sin\theta\cos\theta \cdot \sin\phi$

Note : Number of radial nodes = $n - \ell - 1$

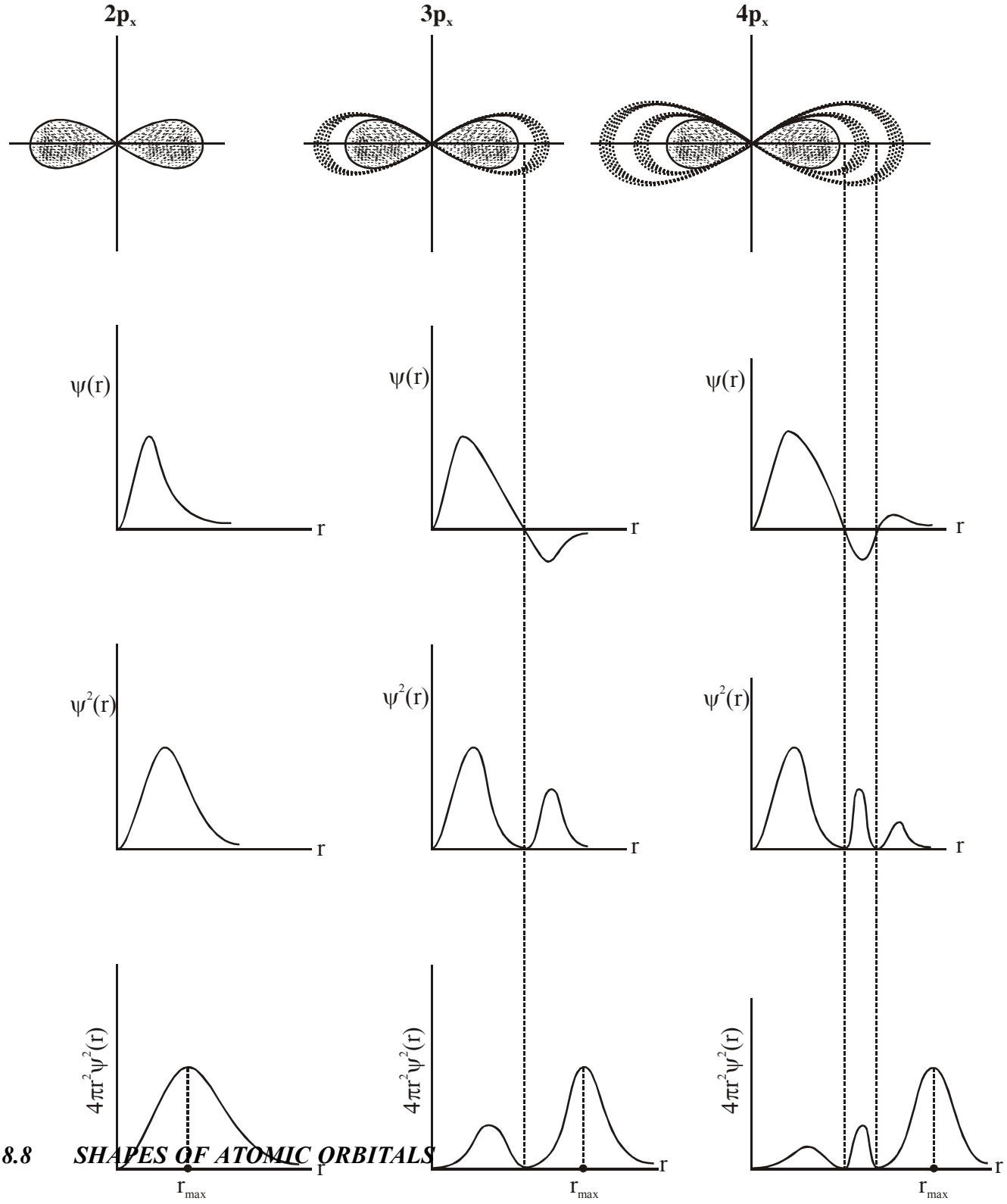
Number of angular nodes = ℓ

Total of number nodes = $n - 1$

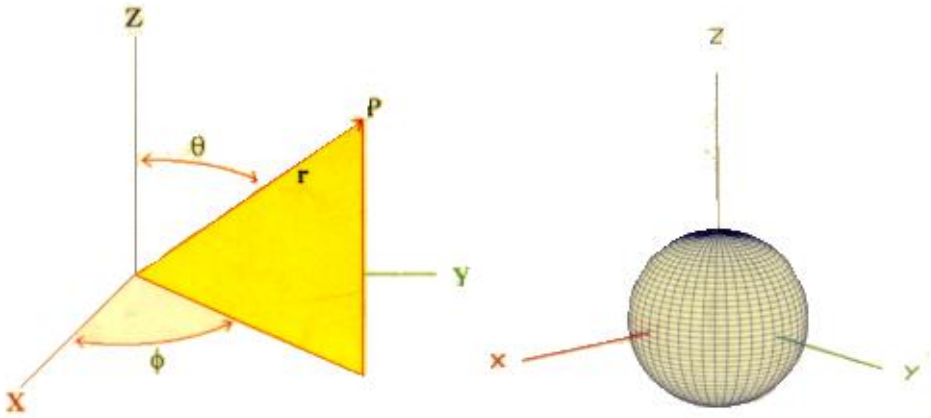
8.6 Electron-density distribution in 1s, 2s and 3s-orbitals. The lower part of the fig. shows how the electron density, represented by ψ^2 varies as a function of distance from the nucleus. In the 2s and 3s - orbitals, the electron-density function drops to zero at certain distances from the nucleus. The spherical surfaces around the nucleus at which ψ^2 is zero are called nodes.



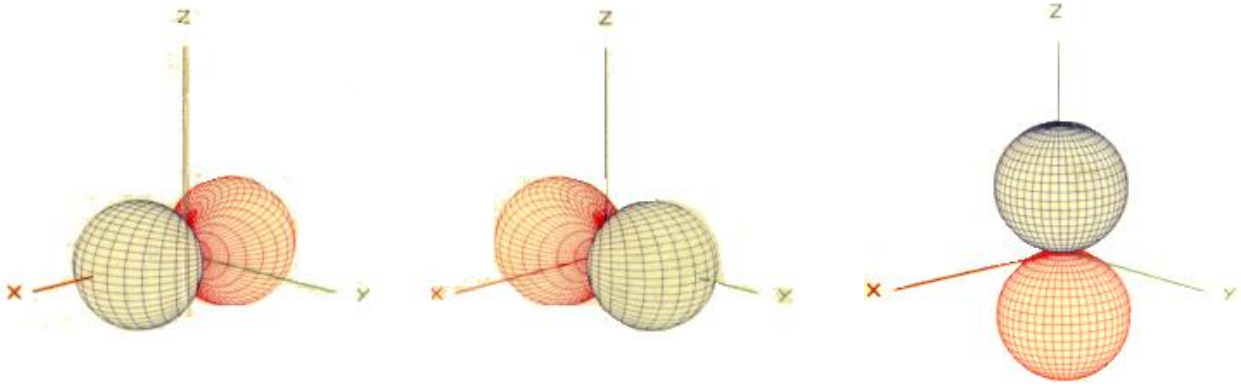
8.7 Electron-density distribution in $2p_x$, $3p_x$ and $4p_x$-orbitals :



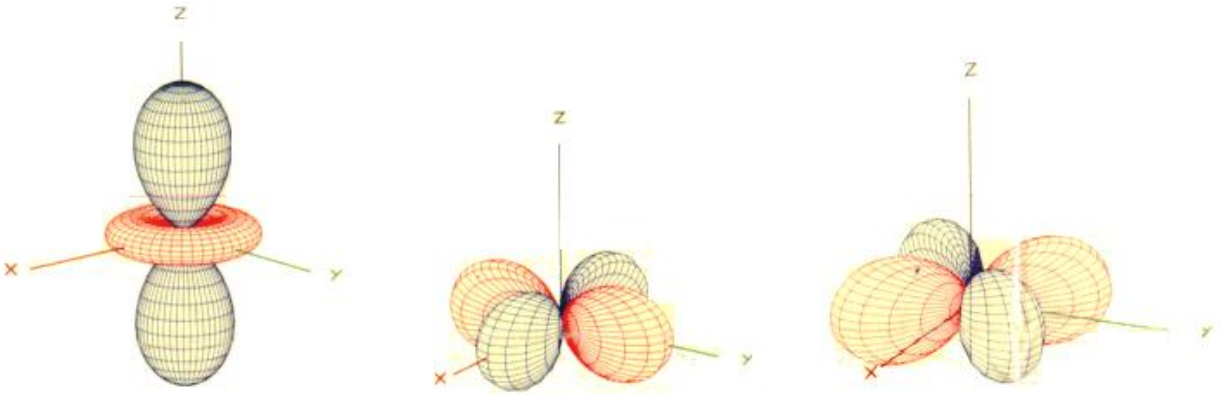
8.8 *SHAPES OF ATOMIC ORBITALS*



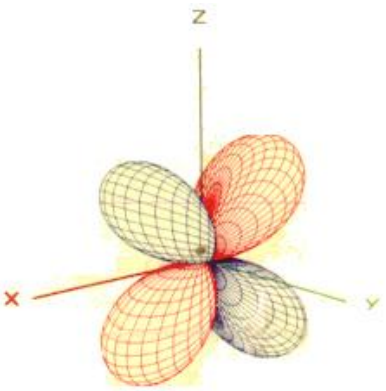
The spherical Polar Coordinates S



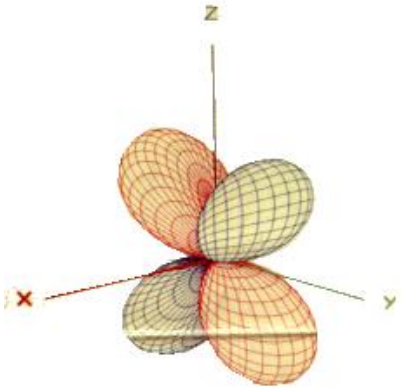
p_X p_y p_z



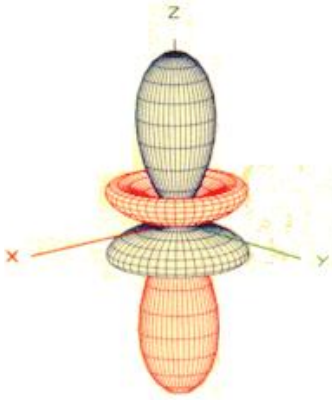
d_{z^2} $d_{x^2-y^2}$ d_{xy}



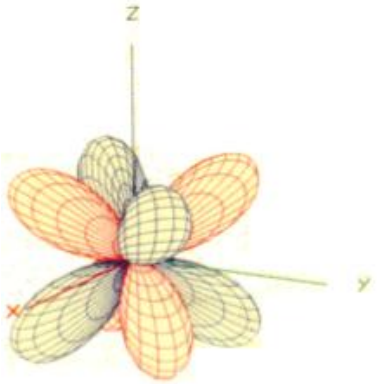
d_{xz}



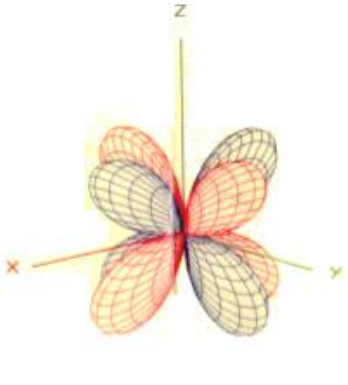
d_{yz}



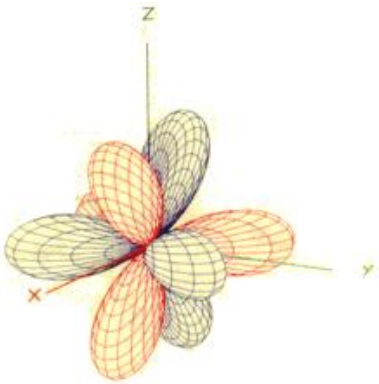
f_{z^3}



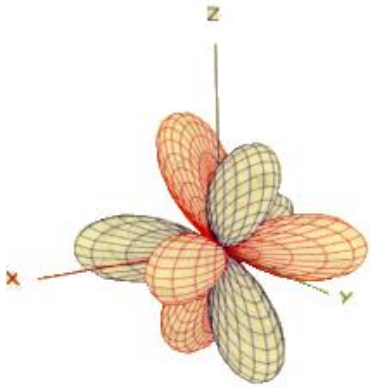
f_{xyz}



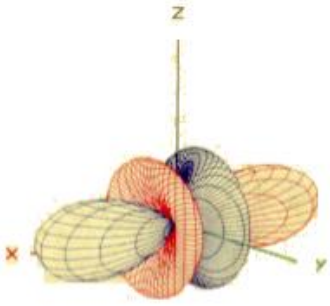
$f_{z(x^2-y^2)}$



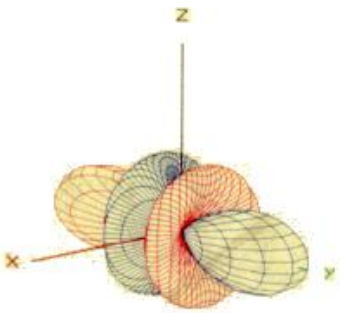
$f_{x(y^2-z^2)}$



$f_{y(z^2-x^2)}$



f_{x^3}



f_{y^3}

Ex.49 Find the distance at which probability of finding electron is maximum for 1s orbital in a He atom. The wave function of orbital is given as.

$$\psi_{1s} = \frac{4}{a_0^{3/2}}.e^{-\frac{2r}{a_0}}$$

Sol. Probability distribution function is $P(r) = \psi^2.4\pi r^2 = \left(\frac{16}{a_0^3}\right)e^{\left(-\frac{4r}{a_0}\right)}.4\pi r^2$

$\Rightarrow$ $P(r) = k\ .\ r^2.e^{\frac{-4r}{a_0}}$

differentating $\frac{dP(r)}{dr} = 2r.e^{-\frac{4r}{a_0}} - \left(\frac{4}{a_0}\right)r^2.e^{-\frac{4r}{a_0}} = 0$

$\Rightarrow$ $1 = \frac{2r}{a_0} \Rightarrow r = \frac{a_0}{2}$

$\Rightarrow$ probability of finding electron is maximum at distance $\frac{a_0}{2}$ from nucleus.

Ex.50 Consider ψ (wave function) of 2s atomic orbital of H-atom is -

$$\psi_{2s} = \frac{1}{4\sqrt{2\pi}\,a_0^{3/2}}\left[2 - \frac{r}{a_0}\right]e^{-\frac{r}{2a_0}}$$

Find distance of radial node from nucleus in terms of a_0.

Sol. $R(r) = 0$

$$\left[2 - \frac{r}{a_0}\right]e^{-\frac{r}{2a_0}} = 0 \ \Rightarrow\ 2 - \frac{r}{a_0} = 0 \ \Rightarrow\ r = 2\,a_0$$

EXERCISE - O

1. Anode rays are made up of :
(A) only protons (B) only nucleus of atom
(C) Positive residue of atoms (D) only electrons

AS0076

2. When Lithium $\left({}^{7}_{3}\mathrm{Li}\right)$ vapours were filled in discharge tube for anode ray experiment, the anode rays were found to contain only Li^+ ions. Thus the anode ray particle contains :
(A) 1 proton only (B) 3 proton and 4 neutron only
(C) 3 proton, 4 neutron and 2 electrons (D) 3 proton, 3 neutrons and 3 electrons

AS0077

3. The specific charge is maximum for
(A) Na^+ (B) Al^{+3} (C) H^+ (D) Mg^{+2}

AS0078

4. Which of the following particle is not deflected in the magnetic field
(A) Electron (B) proton (C) Neutron (D) Deuteron

AS0079

5. E/m ratio of a particle of charge 2 unit and mass 4 amu is
(A) 4.8×10^7 C/kg (B) 0.5 C/kg (C) 4.8×10^4 C/kg (D) 8×10^{-20} C/kg

AS0080

6. α-particles are projected towards the nucleus of following metals, with the same kinetic energy. The distance of closest approach will be minimum for which metal?
(A) Cu (B) Ag (C) Au (D) Ca

AS0081

7. Which of the following is not a conclusion of Rutherford's atomic model -
(A) Most of the part inside an atom is empty
(B) Almost all mass of an atom is concentrated in the nucleus.
(C) The size of nucleus is very small in compartison to the size of atom
(D) Electron revolves around the nucleus in definite orbits.

AS0082

8. In the different experiements, α-particles, proton, deuteron and neutron are projected towards gold nucleus with the same kinetic energy. The distance of closest approach will be minimum for
(A) α-particle (B) proton (C) dueteron (D) neutron

AS0083

9 The ratio of the energy of a photon of 2000 Å wavelength radiation to that of 4000 Å radiation is
(A) 1 / 4 (B) 4 (C) 1 / 2 (D) 2

AS0084

10. Small packets of light is called
(A) proton (B) quanta (C) photon (D) spectrum

AS0085

11. Which of the following electromagnetic radiation have greater frequency ?
(A) X - rays (B) Ultraviolet rays (C) Radio waves (D) Visible rays

AS0086

12. Two electromagnetic radiations have wave numbers in the ratio 2 : 3. Their energies per quanta will be in the ratio
(A) 3 : 2 (B) 9 : 4 (C) 4 : 9 (D) 2 : 3

AS0087

13. A radio station is emitting the radiations of frequency 2×10^4 Hz. If its frequency is doubled,
(A) wavelength will be doubled (B) energy per quanta will be doubled
(C) wave number will be halved (D) all of these

AS0088

14. A photon of 400 nm is absorbed by a gas molecule and then the molecule re-emits two photons. One re-emitted photon has wavelength 500 nm. Assuming that there is no change in the energy of molecule, the wavelength of second re-emitted photon is
(A) 100 nm (B) 2000 nm (C) -100 nm (D) 900 nm

AS0089

15. A green bulb and a red bulb are emitting the radiations with equal power. The correct relation between numbers of photons emitted by the bulbs per second is
(A) $n_g = n_r$ (B) $n_g < n_r$ (C) $n_g > n_r$ (D) unpredictable

AS0090

16. The threshold wavelength for ejection of electrons from a metal is 330 nm. The work function for the photoelectric emission from the metal is ($h = 6.6 \times 10^{-34}$ J-s)
(A) 1.2×10^{-18}J (B) 6.0×10^{-19} J (C) 1.2×10^{-20} J (D) 6.0×10^{-12} J

AS0091

17. In the emission of photoelectrons, the number of photoelectrons emitted per unit time depends upon
(A) energy of the incident radiation (B) intensity of the incident radiation
(C) frequency of the incident radiation (D) wavelength of the incident radiation

AS0092

18. Radiations of frequency, ν , are incident on a photosensitive metal. The maximum kinetic energy of photoelectrons is 'E'. When the frequency of the incident radiations is doubled, what is the maximum kinetic energy of the photoelectrons ?
(A) 2E (B) E/2 (C) E + hv (D) E - hv

AS0093

19. Radiation of λ = 155 nm was irradiated on Li (work function = 5 eV) plate. The stopping potential (in V) is _____.
(A) 3 V (B) 8 V (C) 9 V (D) 5 V

AS0094

20 Electromagnetic radiations having $\lambda = 310$ Å are subjected to a metal sheet having work function = 12.8 eV. What will be the velocity of photoelectrons with maximum Kinetic Energy..
(A) 0, no emission will occur (B) 2.18×10^6 m/s
(C) $2.18\sqrt{2} \times 10^6$ m/s (D) 8.72×10^6 m/s **AS0095**

21. Bohr's model may be applied to
(A) Na^{10+} ion (B) He atom (C) Be^{2+} ion (D) C^{6+} ion

AS0096

22. If the radius of 3rd Bohr's orbit of H is x, then radius of 4th orbit of Li^{2+} ion would be :-

(A) $\frac{27}{16}x$ (B) $\frac{16}{27}x$ (C) $\frac{9}{16}$ (D) None of these

AS0097

23. What would be the approximate quantum number, n, for a circular orbit of hydrogen, 1×10^{-5} cm in diameter ?
(A) 31 (B) 43 (C) 40 (D) 39

AS0098

24. If the mass of electron is doubled, the radius of first orbit of H-atom become about
(A) 0.529 Å (B) 0.265 Å (C) 1.058 Å (D) 0.32 Å

AS0099

25. The speed of electron revolving in the 4th orbit of a hydrogen like atom or ion is 1094 km/s. The atom or ion is
(A) H (B) He^{+} (C) Li^{2+} (D) Be^{3+}

AS0100

26. How much distance an electron revolving in 3rd orbit of He^{+} ion will travel in one second
(A) 1.458×10^{6} m (B) 3.28×10^{6} m (C) 4.862×10^{5} m (D) 2.917×10^{6} m

AS0101

27. The ratio of time taken by electron in revolutions round the H-nucleus in 2nd and 3rd orbits, are
(A) 2 : 3 (B) 4 : 8 (C) 8 : 27 (D) 27 : 8

AS0102

28. Which of the following is not a permissible value of angular momentum of electron in H-atom?

(A) $1.5\ \frac{h}{\pi}$ (B) $0.5\ \frac{h}{\pi}$ (C) $1.25\ \frac{h}{\pi}$ (D) all of these

AS0103

29. Angular momentum for P–shell electron :–

(A) $\frac{3h}{\pi}$ (B) Zero (C) $\frac{\sqrt{2}h}{2\pi}$ (D) None

AS0104

30. Angular momentum in 2nd Bohr orbit of H-atom is x. Then find out angular momentum in Ist excitetd state of Li^{+2} :–
(A) 3x (B) 9x (C) x/2 (D) x

AS0105

31. The orbit from which when electron will jump in other orbit, energy may be absorbed but not emitted out, will be
(A) 1st orbit (B) 2nd orbit (C) 7th orbit (D) infinite orbit

AS0106

32. The potential energy of electron revolving in the ground state of H-atom is
(A) -13.6 eV (B) -6.8 eV (C) -27.2 eV (D) Zero

AS0107

33. If the potential energy (PE) of hydrogen electron is –3.02eV then in which of the following excited level is electron present :-
(A) 1^{st} (B) 2^{nd} (C) 3^{rd} (D) 4^{th}

AS0108

34. A single electron is revolving in orbits around a stationary nucleus (z = 5). The energy required to excite the electron from third to fourth Bohr orbit will be :-
(A) 4.5 eV (B) 8.53 eV (C) 25 eV (D) 16.53 eV

AS0109

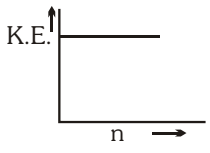
35. A photon of energy 12.75 ev is completely absorbed by a hydrogen atom initially in ground state. The principle quantum number of the excited state is
(A) 1 (B) 3 (C) 4 (D) ∞

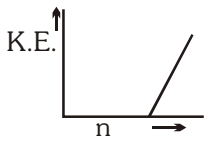
AS0110

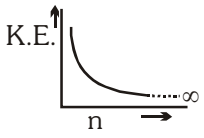
36. An hydrogen atom (ionisation energy 13.6 eV) jumps from third excited state to first excited state. The energy of photon emitted in the process is
(A) 1.89 eV (B) 2.55 eV (C) 12.09 eV (D) 12.75 eV

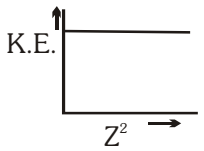
AS0111

37. Which is correct graph :-

(A) 

(B) 

(C) 

(D) 

AS0112

38. The energy required to remove an electron from the surface of sodium metal is 3.3 eV. What is the longest wavelength of radiation with which it can show photoelectric effect?
Use $h = 6.6 \times 10^{-34}$ J.s
(A) 1.75×10^{-7} m (B) 3.75×10^{-5} m (C) 1.75×10^{-5} m (D) 3.75×10^{-7} m

AS0113

39. Which is correct for any H like species :-
(A) $(E_2 - E_1) > (E_3 - E_2) > (E_4 - E_3)$ (B) $(E_2 - E_1) < (E_3 - E_2) < (E_4 - E_3)$
(C) $(E_2 - E_1) = (E_3 - E_2) = (E_4 - E_3)$ (D) $(E_2 - E_1) = 1/4\ (E_3 - E_2) = 1/9\ (E_4 - E_3)$

AS0114

40. A single electron orbits a stationary nucleus of charge +Ze, where Z is a constant. It requires 47.2 eV to excite electron from second Bohr orbit to third Bohr orbit, find the value of Z :-
(A) 1 (B) 3 (C) 5 (D) 4

AS0115

41. The energy of H–atom in n^{th} orbit is E_n then energy in n^{th} orbit of singly ionised helium atom will be:
(A) $4E_n$ (B) $E_n/4$ (C) $2E_n$ (D) $E_n/2$

AS0116

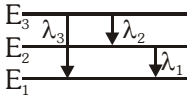
42 Which electronic level would allow the hydrogen atom to absorb a photon but not to emit a photon
(A) 3s (B) 2p (C) 2s (D) 1s

AS0117

43 The third line in Balmer series corresponds to an electronic transition between which Bohr's orbits in hydrogen
(A) $5 \rightarrow 3$ (B) $5 \rightarrow 2$ (C) $4 \rightarrow 3$ (D) $4 \rightarrow 2$

AS0118

44. In the following transition which statement is correct



(A) $E_{3-1} = E_{3-2} - E_{2-1}$ (B) $\lambda_3 = \lambda_1 + \lambda_2$
(C) $\nu_3 = \nu_2 + \nu_1$ (D) All of these

AS0119

45. The first Lyman transition in the hydrogen spectrum has $\Delta E = 10.2$ eV. The same energy change is observed in the second Balmer transition of :-
(A) Li^{2+} (B) Li^{+} (C) He^{+} (D) Be^{3+}

AS0120

46. In a sample of H–atoms, electron transits from 6^{th} orbit to 2^{nd} orbit in multi step. Then total spectral lines (without Balmer series) will be :–
(A) 6 (B) 10 (C) 4 (D) 0

AS0121

47. What is the shortest wavelength in the Pfund series of He^{+} ion :-
(A) $\frac{25}{R}$ (B) $\frac{4}{R}$ (C) $\frac{4R}{25}$ (D) $\frac{25}{4R}$

AS0122

48 The shortest wavelength of He^{+} ion in Balmer series is x, then longest wavelength in the Paschene series of Li^{+2} is
(A) $\frac{36x}{5}$ (B) $\frac{16x}{7}$ (C) $\frac{9x}{5}$ (D) $\frac{5x}{9}$

AS0123

49 The ratio of wave length of photon corresponding to the α-line of Lyman series in H-atom and β-line of Balmer series in He^{+} is
(A) 1 : 1 (B) 1 : 2 (C) 1 : 4 (D) 3 : 16

AS0124

50 Three energy levels P, Q, R of a certain atom are such that $E_P < E_Q < E_R$. If λ_1, λ_2 and λ_3 are the wave length of radiation corresponding to transition $R \rightarrow Q$; $Q \rightarrow P$ and $R \rightarrow P$ respectively. The correct relationship between λ_1, λ_2 and λ_3 is
(A) $\lambda_1 + \lambda_2 = \lambda_3$ (B) $\frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$ (C) $\lambda_3 = \sqrt{\lambda_1 \lambda_2}$ (D) $\frac{2}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$

AS0125

51. Number of possible spectral lines which may be emitted in bracket series in H atom, if electrons present in 9th excited level returns to ground level, are
(A) 21 (B) 6 (C) 45 (D) 5

AS0126

52. The value of $(n_2 + n_1)$ and $\left(n_2^2 - n_1^2\right)$ for He^+ ion in atomic spectrum are 4 and 8 respectively. The wavelength of emitted photon when electron jump from n_2 to n_1 is

(A) $\frac{32}{9} R_H$ (B) $\frac{9}{32} R_H$ (C) $\frac{9}{32 R_H}$ (D) $\frac{32}{9 R_H}$

AS0127

53 An electron, a proton and an alpha particle have kinetic energies of 16E, 4E and E respectively. What is the qualitative order of their de Broglie wavelengths?
(A) $\lambda_e > \lambda_p = \lambda_\alpha$ (B) $\lambda_p = \lambda_\alpha > \lambda_e$ (C) $\lambda_p > \lambda_e > \lambda_\alpha$ (D) $\lambda_\alpha < \lambda_e » \lambda_p$

AS0128

54 The wavelength associated with a golf weighing 200g and moving at a speed of 5m/h is of the order
(A) 10^{-10}m (B) 10^{-20}m (C) 10^{-30}m (D) 10^{-40}m

AS0129

55. An electron has kinetic energy 2.8×10^{-23} J. de-Broglie wavelength will be nearly :-
($m_e = 9.1 \times 10^{-31}$ kg)
(A) 9.28×10^{-24} m (B) 9.28×10^{-7} m (C) 9.28×10^{-8} m (D) 9.28×10^{-10} m

AS0130

56. What will be de-Broglie wavelength of an electron moving with a velocity of 1.2×10^5 ms^{-1}:- (A)
6.068×10^{-9} m (B) 3.133×10^{-37} m (C) 6.626×10^{-9} m (D) 6.018×10^{-7} m

AS0131

57. For a valid Bohr orbit, its circumfrence should be:
(A) $= n\lambda$ (B) $= (n-1)\lambda$ (C) $> n\lambda$ (D) $< n\lambda$

AS0132

58. The number of waves made by a Bohr electron in an orbit of maximum magnetic quantum number + 2 :
(A) 3 (B) 4 (C) 2 (D) 1

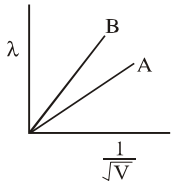
AS0133

59. How fast is an electron moving if it has a wavelength equal to distance travelled in one second -

(A) $\sqrt{\frac{m}{h}}$ (B) $\sqrt{\frac{h}{m}}$ (C) $\sqrt{\frac{h}{p}}$ (D) $\sqrt{\frac{h}{2 \times K.E.}}$

AS0134

60. De-Broglie wavelength of two particles A & B are plotted against $\left(\frac{1}{\sqrt{V}}\right)$; where V is potential on the particles. Which of the following relation is correct about mass of particle (charge is same)
(A) $M_A = M_B$
(B) $M_A > M_B$
(C) $M_A < M_B$
(D) $M_A \leq M_B$



AS0135

61. An α-particle is accelerated through a potential difference of V volts from rest. The de-Broglie's wavelength associated with it is -

(A) $\sqrt{\frac{150}{V}}A^\circ$ (B) $\frac{0.286}{\sqrt{V}}A^\circ$ (C) $\frac{0.101}{\sqrt{V}}A^\circ$ (D) $\frac{0.983}{\sqrt{V}}A^\circ$

AS0136

62 Which quantum number is not related with Schrodinger equation

(A) Principal (B) Azimuthal (C) Magnetic (D) Spin

AS0137

63. Which is true about ψ :-

(A) ψ represents the probability of finding an electron around the nucleus

(B) ψ represent the amplitude of the electron wave

(C) Both A and B (D) None of these

AS0138

64. According to Schrodinger model nature of electron in an atom is as :-

(A) Particles only (B) Wave only

(C) Both simultaneously (D) Sometimes waves and sometimes particle

AS0139

65. The orbital angular momentum of an electron in 2s orbital is:

(A) $+\frac{1}{2}.\frac{\hbar}{2\pi}$ (B) Zero (C) $\frac{\hbar}{2\pi}$ (D) $\sqrt{2}.\frac{\hbar}{2\pi}$

AS0140

66. In an excited state, a calcium atom has the electronic configuration $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 4d^1$. What is the orbital angular momentum for d electron :- $\left(\hbar = \frac{h}{2\pi}\right)$

(A) $\sqrt{4}\hbar$ (B) $\sqrt{16}\hbar$ (C) $\sqrt{6}\hbar$ (D) $\sqrt{10}\hbar$

AS0141

67. Which orbitlal has two angular nodal planes :-

(A) s (B) p (C) d (D) f

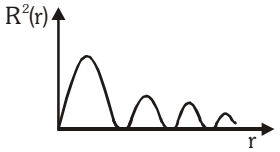
AS0142

68. From the following observations predict the type of orbital :

Observation 1 : x y plane acts as nodal plane

Observation 2 : The angular function of the orbital intersect the three axis at origin only.

Observation 3 : $R^2(r)$ v/s r curve is obtained for the orbital is



(A) $5p_z$ (B) $6d_{xy}$ (C) $6d_{x^2-y^2}$ (D) $6d_{yz}$

AS0143

EXERCISE *J-MAINS*

1. If the kinetic energy of an electron is increased four times, the wavelength of the de-Broglie wave associated with it would become :- **[JEE-Main(online) 2012]**

(1) Two times (2) Half (3) One fourth (4) Four times

AS0171

2. If the radius of first orbit of H atom is a_0, the de-Broglie wavelength of an electron in the third orbit is :- **[JEE-Main(online) 2012]**

(1) $6\ \pi\ a_0$ (2) $8\ \pi\ a_0$ (3) $2\ \pi\ a_0$ (4) $4\ \pi\ a_0$

AS0172

3. The wave number of the first emission line in the Balmer series of H-Spectrum is : (R = Rydberg constant) : **[JEE-Main(online) 2013]**

(1) $\frac{3}{4}R$ (2) $\frac{9}{400}R$ (3) $\frac{5}{36}R$ (4) $\frac{7}{6}R$

AS0173

4. The de Broglie wavelength of a car of mass 1000 kg and velocity 36 km/hr is : ($h = 6.63 \times 10^{-34}$ Js) **[JEE-Main(online) 2013]**

(1) 6.626×10^{-31} m (2) 6.626×10^{-34} m

(3) 6.626×10^{-38} m (4) 6.626×10^{-30} m

AS0174

5. For which of the following particles will it be most difficult to experimentally verify the de-Broglie relationship? **[JEE-Main(online) 2014]**

(1) a dust particle (2) an electron (3) a proton (4) an α-particle.

AS0175

6. If the binding energy of the electron in a hydrogen atom is 13.6 eV, the energy required to remove the electron from the first excited state of Li^{++} is : **[JEE-Main(online) 2014]**

(1) 13.6 eV (2) 30.6 eV (3) 122.4 eV (4) 3.4 eV

AS0176

7. Based on the equation **[JEE-Main(online) 2014]**

$$\Delta E = -2.0\times10^{-18}\,J\left(\frac{1}{n_2^2}-\frac{1}{n_1^2}\right)$$

the wavelength of the light that must be absorbed to excite hydrogen electron from level n = 1 to level n = 2 will be ($h = 6.625 \times 10^{-34}$ Js, $C = 3 \times 10^8$ ms^{-1}) **[JEE-Main(online) 2014]**

(1) 2.650×10^{-7} m (2) 1.325×10^{-7} m

(3) 1.325×10^{-10} m (4) 5.300×10^{-10} m

AS0177

8. If λ_0 and λ be the threshold wavelength and wavelength of incident light, the velocity of photoelectron ejected from the metal surface is **[JEE-Main(online) 2014]**

(1) $\sqrt{\frac{2hc}{m}\left(\frac{\lambda_0-\lambda}{\lambda\lambda_0}\right)}$ (2) $\sqrt{\frac{2h}{m}\left(\frac{1}{\lambda_0}-\frac{1}{\lambda}\right)}$ (3) $\sqrt{\frac{2h}{m}(\lambda_0-\lambda)}$ (4) $\sqrt{\frac{2hc}{m}(\lambda_0-\lambda)}$

AS0178

9. Ionization energy of gaseous Na atoms is 495.5 kjmol^{-1}. The lowest possible frequency of light that ionizes a sodium atom is
(h = 6.626 × 10^{-34} Js, N_A = 6.022 × 10^{23} mol^{-1}) **[JEE-Main(online) 2014]**
(1) 3.15 × 10^{15} s^{-1} (2) 4.76 × 10^{14} s^{-1} (3) 1.24 × 10^{15} s^{-1} (4) 7.50 × 10^{4} s^{-1}

AS0179

10. Which of the following is the energy of a possible excited state of hydrogen?
[JEE-Main(offline) 2015]
(1) –3.4 eV (2) +6.8 eV (3) +13.6 eV (4) –6.8 eV

AS0180

11. At temperature T, the average kinetic energy of any particle is $\frac{3}{2}$ kT- The de Broglie wavelength follows the order : **[JEE-Main(online) 2015]**
(1) Visible photon > Thermal electron > Thermal neutron
(2)Thermal proton > Thermal electron > Visible photon
(3)Visible photon > Thermal neutron > Thermal electron
(4) Thermal proton > Visible photon > Thermal electron

AS0181

12. A stream of electrons from a heated filament was passed between two charged plates kept at a potential difference V volts. If e and m are charge and mass of an electron respectively, then the value of h/λ (where λ is wavelength associated with electron wave) is given by : **[JEE-Main(online) 2016]**
(1) $\sqrt{2meV}$ (2) meV (3) 2meV (4) $\sqrt{meV}$

AS0182

13. The radius of the second Bohr orbit for hydrogen atom is : **[JEE-Main(offline) 2017]**
(Plank's const. h = 6.6262 × 10^{-34} Js ; mass of electron = 9.1091 × 10^{-31} kg ; charge of electron e = 1.60210 × 10^{-19} C ; permittivity of vaccum
ϵ_0 = 8.854185 × 10^{-12} kg^{-1} m^{-3} A^2)
(1) 1.65Å (2) 4.76Å (3) 0.529Å (4) 2.12Å

AS0183

14. If the shortest wavelength in Lyman series of hydrogen atom is A, then the longest wavelength in Paschen series of He^+ is : **[JEE-Main(online) 2017]**
(1) $\frac{36A}{5}$ (2) $\frac{9A}{5}$ (3) $\frac{36A}{7}$ (4) $\frac{5A}{9}$

AS0184

15. The electron in the hydrogen atom undergoes transition from higher orbitals to orbital of radius 211.6 pm. This transition is associated with:- **[JEE-Main(online) 2017]**
(1) Brackett series (2) Balmer series (3) Lyman series (4) Paschen series

AS0185

16. The de-Broglie's wavelength of electron present in first Bohr orbit of 'H' atom is :-
[JEE-Main(online) 2018]
(1) $\frac{0.529}{2\pi}$ Å (2) 2p × 0.529Å (3) 0.529Å (4) 4×0.529Å

AS0186

17. Ejection of the photoelectron from metal in the photoelectric effect experiment can be stopped by applying 0.5 V when the radiation of 250 nm is used. The work function of the metal is :
(1) 5 eV (2) 4 eV (3) 5.5 eV (4) 4.5 eV **[JEE-Main(online) 2018]**

AS0187

18. Which of the following statements is false ? **[JEE-Main(online) 2018]**
(1) Photon has momentum as well as wavelength.
(2) Splitting of spectral lines in electrical field is called Stark effect.
(3) Frequency of emitted radiation from a black body goes from a lower wavelength to higher wavelength as the temperature increases.
(4) Rydberg constant has unit of energy.

AS0188

19. If p is the momentum of the fastest electron ejected from a metal surface after the irradiation of light having wavelength λ, then for 1.5 p momentum of the photoelectron, the wavelength of the light should be:
[JEE-Main(online) 2019]
(Assume kinetic energy of ejected photoelectron to be very high in comparison to work function)
(1) $\frac{1}{2}\lambda$ (2) $\frac{3}{4}\lambda$ (3) $\frac{2}{3}\lambda$ (4) $\frac{4}{9}\lambda$

AS0189

20. The quantum number of four electrons are given below - **[JEE-Main(online) 2019]**
I. $n = 4, l = 2, m_l = -2, m_s = -\frac{1}{2}$ II. $n = 3, l = 2, m_l = 1, m_s = +\frac{1}{2}$
III. $n = 4, l = 1, m_l = 0, m_s = +\frac{1}{2}$ IV. $n = 3, l = 1, m_l = 1, m_s = -\frac{1}{2}$
The correct order of their increasing energies will be -
(1) IV < III < II < I (2) IV < II < III < I (3) I < II < III < IV (4) I < III < II < IV

AS0190

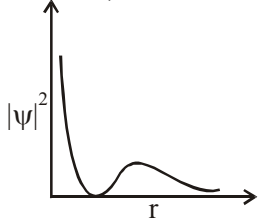
21. For any given series of spectral lines of atomic hydrogen, let $\Delta\bar{\nu} = \bar{\nu}_{max} - \bar{\nu}_{min}$ be the difference in maximum and minimum frequencies in cm^{-1}. The ratio $\Delta\bar{\nu}_{Lyman} / \Delta\bar{\nu}_{Balmer}$ is :
(1) 27 : 5 (2) 4 : 1 **[JEE-Main(online) 2019]**
(3) 5 : 4 (4) 9 : 4

AS0191

22. The ratio of the shortest wavelength of two spectral series of hydrogen spectrum is found to be about 9. The spectral series are: **[JEE-Main(online) 2019]**
(1) Paschen and P fund (2) Lyman and Paschen
(3) Brackett and Piund (4) Balmer and Brackett

AS0192

23. The graph betweeen $|\psi|^2$ and r(radial distance) is shown below. This represents :-



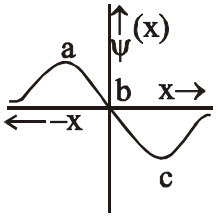
(1) 3s orbital (2) 1s orbital **[JEE-Main(online) 2019]**
(3) 2p orbital (4) 2s orbital

AS0193

24. Among the following, the energy of 2s orbital is lowest in : **[JEE-Main(online) 2019]**
(1) K (2) Na (3) Li (4) H

AS0194

25. The electrons are more likely to be found : **[JEE-Main(online) 2019]**



(1) in the region a and b (2) in the region a and c
(3) only in the region c (4) only in the region a

AS0195

26. What is the work function of the metal if the light of wavelength 4000 Å generates photoelectrons of velocity 6×10^5 ms^{-1} form it ? **[JEE-Main(online) 2019]**
(Mass of electron = 9×10^{-31} kg
Velocity of light = 3×10^8 ms^{-1}
Planck's constant = 6.626×10^{-34} Js
Charge of electron = 1.6×10^{-19} JeV^{-1})
(1) 0.9 eV (2) 4.0 eV (3) 2.1 eV (4) 3.1 eV

AS0196

27. If the de Broglie wavelength of the electron in n^{th} Bohr orbit in a hydrogenic atom is equal to $1.5\ \pi a_0$ (a_0 is Bohr radius), then the value of n/z is : **[JEE-Main(online) 2019]**
(1) 1.0 (2) 0.75 (3) 0.40 (4) 1.50

AS0197

28. The upper stratosphere consisting of the ozone layer protects us from the sun's radiation that falls in the wavelength region of : **[JEE-Main(online) 2019]**
(1) 600-750 nm (2) 0.8-1.5 nm (3) 400-550 nm (4) 200-315 nm

AS0198

29. Heat treatment of muscular pain involves radiation of wavelength of about 900 nm. Which spectral line of H-atom is suitable for this purpose ? **[JEE-Main(online) 2019]**
[$R_H = 1 \times 10^5$ cm^{-1}, $h = 6.6 \times 10^{-34}$ Js, $c = 3 \times 10^8$ ms^{-1}]
(1) Paschen, $5 \rightarrow 3$ (2) Paschen, $\infty \rightarrow 3$ (3) Lyman, $\infty \rightarrow 1$ (4) Balmer, $\infty \rightarrow 2$

AS0199

30. The de Broglie wavelength (λ) associated with a photoelectron varies with the frequency (ν) of the incident radiation as, [ν_0 is thershold frequency] : **[JEE-Main(online) 2019]**

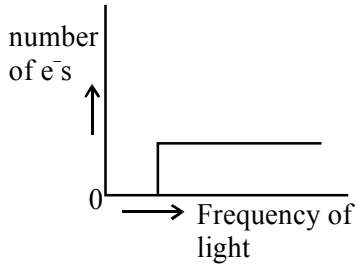
(1) $\lambda \propto \frac{1}{(\nu - \nu_0)^{\frac{3}{2}}}$ (2) $\lambda \propto \frac{1}{(\nu - \nu_0)^{\frac{1}{2}}}$ (3) $\lambda \propto \frac{1}{(\nu - \nu_0)^{\frac{1}{4}}}$ (4) $\lambda \propto \frac{1}{(\nu - \nu_0)}$

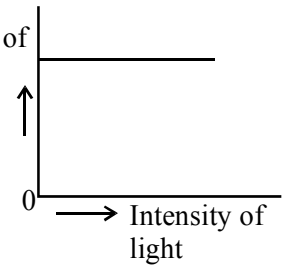
AS0200

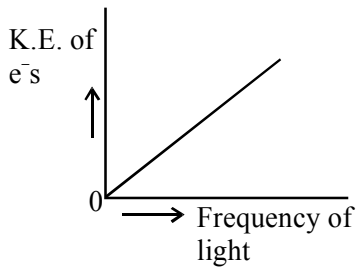
31. The ground state energy of hydrogen atom is –13.6 eV. The energy of second excited state He^+ ion in eV is : **[JEE-Main(online) 2019]**
(1) –6.04 (2) –27.2 (3) –54.4 (4) –3.4

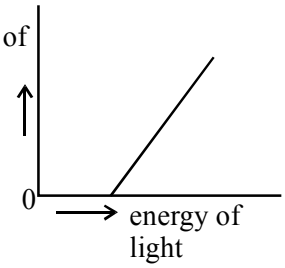
AS0201

32. Which of the graphs shown below does not represent the relationship between incident light and the electron ejected form metal surface ? **[JEE-Main(online) 2019]**

(1) 

(2) 

(3) 

(4) 

AS0202

33. Which of the following combination of statements is true regarding the interpretation of the atomic orbitals ? **[JEE-Main(online) 2019]**

(a) An electron in an orbital of high angular momentum stays away from the nucleus than an electron in the orbital of lower angular momentum.

(b) For a given value of the principal quantum number, the size of the orbit is inversely proportional to the azimuthal quantum number.

(c) According to wave mechanics, the ground state angular momentum is equal to $\frac{h}{2\pi}$.

(d) The plot of ψ Vs r for various azimuthal quantum numbers, shows peak shifting towards higher r value.

(1) (b), (c) (2) (a), (d) (3) (a), (b) (4) (a), (c)

AS0203

34. For emission line of atomic hydrogen from $n_i = 8$ to $n_f = n$ the plot of wave number $(\bar{\nu})$ against $\left(\frac{1}{n^2}\right)$ will be (The Rydberg constant, R_H is in wave number unit). **[JEE-Main(online) 2019]**

(1) Linear with slope - R_H (2) Linear with intercept - R_H

(3) Non linear (4) Linear with slope R_H

AS0204

35. The region in the electromagnetic spectrum where the Balmer series lines appear is **[JEE-Main(online) 2020]**

(1) Visible (2) Microwave (3) Ultraviolet (4) Infrared

AS0225

36. The correct statement about probability density (except at infinite distance from nucleus) is : **[JEE-Main(online) 2020]**

(1) It cn be negative for 2p orbital (2) It can be zero for 3p orbital

(3) It can be zero for 1s orbital (4) It can never be zero for 2s orbital

AS0226

37. The difference between the radii of 3rd and 4th orbits of Li^{2+} is ΔR_1. The difference between the radii of 3rd and 4th orbits of He^+ is ΔR_2. Ratio $\Delta R_1 : \Delta R_2$ is : **[JEE-Main(online) 2020]**

(1) 8 : 3 (2) 3 : 2 (3) 3 : 8 (4) 2 : 3

AS0227

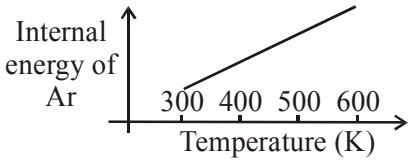
38. The work function of sodium metal is 4.41×10^{-19} J. If the photons of wavelength 300 nm are incident on the metal, the kinetic energy of the ejected electrons will be **[JEE-Main(online) 2020]**

($h = 6.63 \times 10^{-34}$ Js; $c = 3 \times 10^8$ m/s) _____ $\times 10^{-21}$ J.

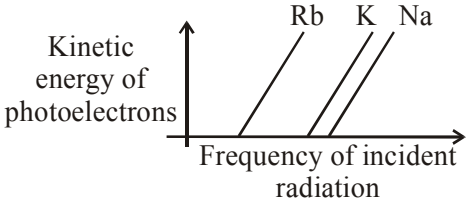
AS0228

39. The figure that is not a direct manifestation of the quantum nature of atoms is : **[JEE-Main(online) 2020]**

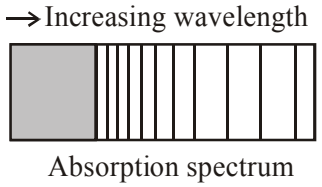
(1)



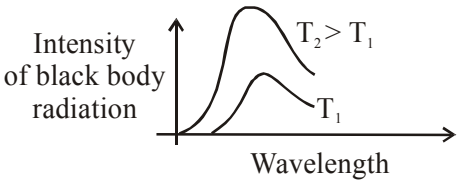
(2)



(3)



(4)



AS0229

40. The metal mainly used in devising photoelectric cells is: **[JEE-Main(online) 2020]**

(1) Na (2) Rb (3) Li (4) Cs

AS0230

41. The shortest wavelength of H atom is the Lyman series is λ_1. The longest wavelength in the Balmer series of He^+ is :- **[JEE-Main(online) 2020]**

(1) $\frac{5\lambda_1}{9}$ (2) $\frac{27\lambda_1}{5}$ (3) $\frac{9\lambda_1}{5}$ (4) $\frac{36\lambda_1}{5}$

AS0231

EXERCISE J-ADVANCE

Paragraph for questions 1 to 3

The hydrogen-like species Li^{2+} is in a spherically symmetric state S_1 with one radial node. Upon absorbing light the ion undergoes transition to a state S_2. The state S_2 has one radial node and its energy is equal to the ground state energy of the hydrogen atom. **[JEE 2010]**

1. The state S_1 is :-
(A) 1s (B) 2s (C) 2p (D) 3s

AS0209

2. Energy of the state S_1 in units of the hydrogen atom ground state energy is :-
(A) 0.75 (B) 1.50 (C) 2.25 (D) 4.50

AS0210

3. The orbital angular momentum quantum number of the state S_2 is :-
(A) 0 (B) 1 (C) 2 (D) 3

AS0211

4. The maximum number of electrons that can have principal quantum number, n=3, and spin quantum number, $m_s = -1/2$, is **[JEE 2011]**

AS0212

5. The work function (ϕ) of some metals is listed below. The number of metals which will show photoelectric effect when light of 300 nm wavelength falls on the metal is : :- **[JEE 2011]**

Metal	Li	Na	K	Mg	Cu	Ag	Fe	Pt	W
ϕ(eV)	2.4	2.3	2.2	3.7	4.8	4.3	4.7	6.3	4.75

AS0213

6. The kinetic energy of an electron in the second Bohr orbit of a hydrogen atom is [a_0 is Bohr radius] **[JEE 2012]**

(A) $\frac{h^2}{4\pi^2 m a_0^2}$ (B) $\frac{h^2}{16\pi^2 m a_0^2}$ (C) $\frac{h^2}{32\pi^2 m a_0^2}$ (D) $\frac{h^2}{32\pi^2 m a_0^2}$

AS0214

7. The atomic masses of He and Ne are 4 and 20 a.m.u. respectively. The value of the de Broglie wavelength of He gas at –73 ºC is "M" times that of the de Broglie wavelength of Ne at 727 ºC. M is.

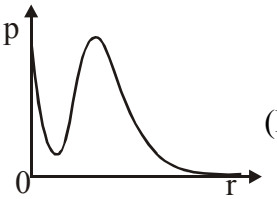
[JEE 2013]

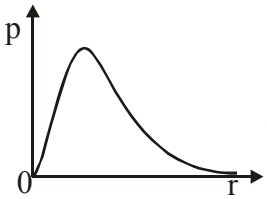
AS0215

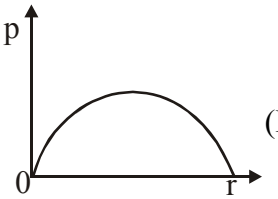
8. In an atom, the total number of electrons having quantum numbers n = 4, $|m_\ell| = 1$ and $m_s = -\frac{1}{2}$ is **[JEE 2014]**

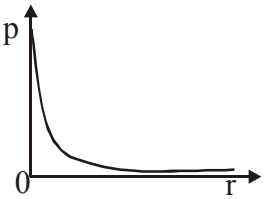
AS0216

9. P is the probability of finding the 1s electron of hydrogen atom in a spherical shell of infinitesimal thickness, dr, at a distance r from the nucleus. The volume of this shell is $4\pi r^2 dr$. The qualitative sketch of the dependence of P on r is - **[JEE 2016]**

(A) 

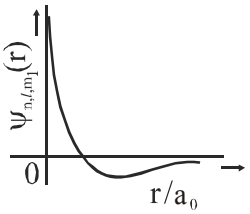
(B) 

(C) 

(D) 

AS0217

Answer Q.10, Q.11 and Q.12 by appropriately matching the information given in the three columns of the following table.
[JEE 2017]

Column-1	Column-2	Column-3
(I) 1s orbital	(i) $\Psi_{n,l,m_l} \propto \left(\frac{Z}{a_0}\right)^{\frac{3}{2}} e^{-\left(\frac{Zr}{a_e}\right)}$	(P) 
(II) 2s orbital	(ii) One radial node	(Q) Probability density at nucleus $\propto \frac{1}{a_0^3}$
(III) $2p_z$ orbital	(iii) $\Psi_{n,l,m_l} \propto \left(\frac{Z}{a_0}\right)^{\frac{5}{2}} re^{-\left(\frac{Zr}{2a_0}\right)} \cos\theta$	(R) Probability density is maximum at nucleus
(IV) $3d_z^2$ orbital	(iv) xy - plane is a nodal plane	(S) Energy needed to excite electron from n = 2 state to n = 4 state is $\frac{27}{32}$ times the energy needed to excite electron from n = 2 state to n = 6 state

10. For the given orbital in column 1, the only **CORRECT** combination for any hydrogen - like species is :
(A) (IV) (iv) (R) (B) (II) (ii) (P) (C) (III) (iii) (P) (D) (I) (ii) (S)
AS0218

11. For He^+ ion, the only **INCORRECT** combination is
(A) (II) (ii) (Q) (B) (I) (i) (S) (C) (I) (i) (R) (D) (I) (iii) (R)
AS0219

12. For hydrogen atom, the only **CORRECT** combination is
(A) (I) (iv) (R) (B) (I) (i) (P) (C) (II) (i) (Q) (D) (I) (i) (S)
AS0220

13. The ground state energy of hydrogen atom is –13.6 eV. Consider an electronic state Ψ of He^+ whose energy, azimuthal quantum number and magnetic quantum number are –3.4 eV, 2 and 0 respectively. Which of the following statement(s) is(are) true for the state Ψ? **[JEE 2019]**
(1) It has 2 angular nodes
(2) It has 3 radial nodes
(3) It is a 4d state
(4) The nuclear charge experienced by the electron in this state is less than 2e, where e is the magnitude of the electronic charge.
AS0221

14. Answer the following by appropriately matching the lists based on the information given in the paragraph [JEE 2019]

Consider the Bohr's model of a one-electron atom where the electron moves around the nucleus. In the following List-I contains some quantities for the n^{th} orbit of the atom and List-II contains options showing how they depend on n.

	List-I	List-II
(I)	Radius of the n^{th} orbit	**(P)** $\propto n^{-2}$
(II)	Angular momentum of the electron in the n^{th} orbit	**(Q)** $\propto n^{-1}$
(III)	Kinetic energy of the electron in the n^{th} orbit	**(R)** $\propto n^{0}$
(IV)	Potential energy of the electron in the n^{th} orbit	**(S)** $\propto n^{1}$
		(T) $\propto n^{2}$
		(U) $\propto n^{1/2}$

Which of the following options has the correct combination considering List-I and List-II?

(1) (II), (R) (2) (I), (P) (3) (I), (T) (4) (II), (Q)

AS0222

15. Answer the following by appropriately matching the lists based on the information given in the paragraph [JEE 2019]

Consider the Bohr's model of a one-electron atom where the electron moves around the nucleus. In the following List-I contains some quantities for the n^{th} orbit of the atom and List-II contains options showing how they depend on n.

	List-I	List-II
(I)	Radius of the n^{th} orbit	**(P)** $\propto n^{-2}$
(II)	Angular momentum of the electron in the n^{th} orbit	**(Q)** $\propto n^{-1}$
(III)	Kinetic energy of the electron in the n^{th} orbit	**(R)** $\propto n^{0}$
(IV)	Potential energy of the electron in the n^{th} orbit	**(S)** $\propto n^{1}$
		(T) $\propto n^{2}$
		(U) $\propto n^{1/2}$

Which of the following options has the correct combination considering List-I and List-II?

(1) (III), (S) (2) (IV), (Q) (3) (IV), (U) (4) (III), (P)

AS0223

ANSWER KEY

EXERCISE O

1.	Ans.(C)	2.	Ans.(C)	3.	Ans.(C)	4.	Ans.(C)
5.	Ans.(A)	6.	Ans.(D)	7.	Ans.(D)	8.	Ans.(D)
9.	Ans.(D)	10.	Ans.(C)	11.	Ans.(A)	12.	Ans.(D)
13.	Ans.(B)	14.	Ans.(B)	15.	Ans.(B)	16.	Ans.(B)
17.	Ans.(B)	18.	Ans.(C)	19.	Ans. (A)	20.	Ans.(C)
21.	Ans.(A)	22.	Ans.(B)	23.	Ans.(A)	24.	Ans.(B)
25.	Ans.(B)	26.	Ans.(A)	27.	Ans.(C)	28.	Ans.(C)
29.	Ans.(A)	30	Ans.(D)	31.	Ans.(A)	32.	Ans.(C)
33.	Ans.(B)	34.	Ans.(D)	35.	Ans.(C)		
36.	Ans.(B)	37.	Ans.(C)	38.	Ans.(D)	39.	Ans.(A)
40.	Ans.(C)	41.	Ans.(A)	42	Ans.(D)	43.	Ans.(B)
44.	Ans.(C)	45.	Ans.(C)	46.	Ans.(A)	47.	Ans.(D)
48.	Ans.(B)	49.	Ans.(A)	50.	Ans.(B)	51.	Ans.(B)
52.	Ans.(C)	53.	Ans.(A)	54.	Ans.(C)	55.	Ans.(C)
56.	Ans.(A)	57.	Ans.(A)	58.	Ans.(A)	59.	Ans(B)
60	Ans.(B)	61.	Ans.(C)	62	Ans.(D)	63.	Ans.(B)
64.	Ans.(C)	65.	Ans.(B)	66.	Ans.(C)	67.	Ans.(C)
68.	Ans.(D)						

EXERCISE J-MAINS

1.	Ans.(2)	2.	Ans.(1)	3.	Ans.(3)	4.	Ans.(3)
5.	Ans.(1)	6.	Ans.(2)	7.	Ans.(2)	8.	Ans.(1)
9.	Ans.(3)	10.	Ans.(1)	11.	Ans.(1)	12.	Ans.(1)
13.	Ans.(4)	14.	Ans.(3)	15.	Ans.(2)	16.	Ans.(2)
17.	Ans.(4)	18	Ans.(3)	19.	Ans.(4)	20.	Ans.(2)
21.	Ans.(4)	22.	Ans.(2)	23.	Ans.(4)	24.	Ans.(1)
25.	Ans.(2)	26.	Ans.(3)	27.	Ans.(2)	28.	Ans.(4)
29.	Ans.(2)	30.	Ans.(2)	31.	Ans.(1)	32.	Ans.(3)
33.	Ans.(4)	34.	Ans.(4)	35.	Ans.(1)	36.	Ans.(2)
37.	Ans.(4)	38.	Ans.(222.00)	39.	Ans.(1)	40.	Ans.(4)
41.	Ans.(3)						

EXERCISE J-ADVANCE

1.	Ans.(B)	2.	Ans.(C)	3.	Ans.(B)	4.	Ans.(9)
5.	Ans.(4)	6.	Ans.(C)	7.	Ans.(5)	8.	Ans.(6)
9.	Ans.(B)	10.	Ans.(B)	11.	Ans.(D)	12.	Ans. (D)
13.	Ans. (1,3)	14.	Ans.(3)	15.	Ans.(4)		