

## CHAPTER - 02

# STRUCTURE OF ATOM

### SYNOPSIS

#### ELECTRON

It was discovered in cathode rays. Cathode rays are formed when about 5000 - 10000 volts are applied on a gas at about 0.01 mm pressure in a discharge tube

Mass electron =  $9.1 \times 10^{-31} \text{ kg}$  or  $0.00054 \text{ u}$

Charge of electron =  $1.602 \times 10^{-19} \text{ C}$

Specific charge,  $e/m = 1.76 \times 10^{11} \text{ C / kg}$

Cathode rays from different gases or electrodes in the discharge tube have almost the same  $e/m$

Charge was determined by Millikan

Mass and  $e/m$  were determined by J.J. Thomson. Cathode rays originate from the cathode

#### PROTON

It was discovered in anode rays. Anode rays are formed by the ionisation of the gas in the discharge tube. Anode rays from different gases have different  $e/m$ . Highest value is for proton from hydrogen gas

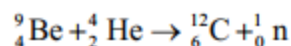
Mass of proton =  $1.672 \times 10^{-27} \text{ kg}$  or  $1.00728 \text{ u}$

Charge of proton =  $1.602 \times 10^{-19} \text{ C}$

$e/m$  ratio of proton =  $9.58 \times 10^7 \text{ C/kg}$

#### NEUTRON

It was discovered by artificial transmutation by James Chadwick



Mass of neutron =  $1.675 \times 10^{-27} \text{ Kg}$  or  $1.00866 \text{ u}$

### Thomson model of atom (Watermelon or Plum pudding or Raisin pudding model)

An atom is a sphere in which the positive charge is distributed uniformly. The electrons are occupying certain positions inside the sphere.

This model could not explain Rutherford's  $\alpha$  particle scattering experiment

### Rutherford's experiment and atomic model

When  $\alpha$  particles were scattered by a gold foil, it was observed that

- (i) most of the particles passed through the foil without considerable deviation
- (ii) a few particles were scattered through small angles
- (iii) a very small number of particles were scattered through  $180^\circ$

Rutherford concluded that an atom has a very small, positively charged and high density nucleus at its centre. Most of the space inside the atom is empty. Electrons move around the nucleus like planets move around sun. The centrifugal force due to circular motion of the electron balances the electrostatic force of attraction

Rutherford model cannot explain

- (i) Stability of the atom
- (ii) atomic spectrum of hydrogen

### **NUCLEUS**

The radius of the nucleus is of the order of  $10^{-15}$  m (one fermi)

The radius of an atom is of the order of  $10^{-10}$  m

Different nuclei have radii in the range 1.5 fermi-6.5 fermi

Radius of any nucleus,  $r = r_0 A^{1/3}$ .  $r_0$  is about 1.4 fermi and A is the mass number

Density of the nucleus is about  $10^{17}$  kg/m<sup>3</sup> or  $10^{14}$  g/cm<sup>3</sup>

### **Atomic number (Z)**

It is the number of protons in an atom

### **Isotopes**

These are the different atoms of the same element having same atomic number but different mass numbers.

ie., isotopes have same number of protons but different number of neutrons.

Eg. (i)  ${}_1\text{H}^1$ ,  ${}_1\text{H}^2$ ,  ${}_1\text{H}^3$  (ii)  ${}_{17}\text{Cl}^{35}$ ,  ${}_{17}\text{Cl}^{37}$

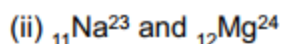
### **Isobars**

These are the atoms of the different elements having same mass number but different atomic numbers.

Eg. (i)  ${}_{19}\text{K}^{40}$  and  ${}_{20}\text{Ca}^{40}$  (ii)  ${}_6\text{C}^{14}$  and  ${}_7\text{N}^{14}$

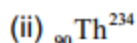
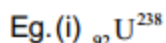
### Isotones

The atoms with same number of neutrons but different number of protons (atomic number) are called isotones.



### Isodiaphers

They are atoms having the same isotopic number or isotopic excess mass (no. of neutrons - no. of protons).



### Characteristics of waves

1. Wavelength ( $\lambda$ ) : Distance between two adjacent crests or troughs is called wavelength. It is expressed in angstrom,  $\text{\AA}$  or in nanometer.

$$1\text{\AA} = 10^{-10}\text{m or } 10^{-8}\text{cm}$$

$$1\text{nm} = 10^{-9}\text{m or } 10^{-7}\text{cm}$$

2. Frequency ( $\nu$ ) : The number of waves passing through a point in one second is called frequency. Its unit is CPS (Cycles Per Second) or Hertz.

$$1\text{CPS} = 1\text{Hz.}$$

3. Velocity ( $C$ ) : The distance traveled by a wave in one second is called velocity.

$$\lambda, \nu \text{ and } C \text{ are related as } C = \nu \lambda.$$

$$\text{For all electromagnetic radiations, } C = 3 \times 10^8 \text{ m/s.}$$

4. Wave number : ( $\bar{\nu}$ )

The number of wave lengths per cm is called wave number. It is equal to the inverse of wave length.

$$\text{ie., } \bar{\nu} = 1/\lambda$$

### Planck's quantum theory

- 1) The energy of a photon is directly proportional to its frequency ie.  $E = h\nu$

$$\text{OR } E = \frac{hc}{\lambda} \quad \text{OR } E = hc\bar{\nu}$$

- 2) Radiant energy is absorbed and emitted by atoms and molecules only discontinuously. ie, as multiples of a certain minimum quantity called one quantum. It is the energy of a photon. ie,  $E = h\nu$ . So the total amount of energy absorbed or radiated =  $n h\nu$ , where  $n=1, 2, 3$  etc.

### Wave-particle dual nature of radiation - proposed by Einstein

Examples of wave properties - diffraction, interference etc.

Examples of particle properties - photoelectric effect, black body radiation, Compton effect etc.

**Photoelectric effect :**

Phenomenon of ejection of electrons from a metal surface when light of suitable frequency strikes on it. The minimum frequency of light required to produce photoelectric effect is called threshold frequency. The energy with which an electron is bound in an atom in metals is called binding energy. The energy required or work to be done to remove an electron from a metal atom is called work function. Energy of threshold frequency photon = work function = binding energy.

K.E. of the photoelectron =  $h(\nu - \nu_0)$  where  $\nu$  is the frequency of the incident radiation and  $\nu_0$  is the

threshold frequency or K.E. =  $hc \left[ \frac{1}{\lambda} - \frac{1}{\lambda_0} \right]$  where  $\lambda$  and  $\lambda_0$  are wavelengths corresponding to  $\nu$  and

$\nu_0$ . Number of photoelectrons ejected  $\propto$  intensity of light. K.E.  $\propto$  frequency of the incident radiation.

**Electromagnetic Spectrum**

The arrangement of different types of electromagnetic radiations in the order of increasing wavelength or decreasing frequency is called electromagnetic spectrum.

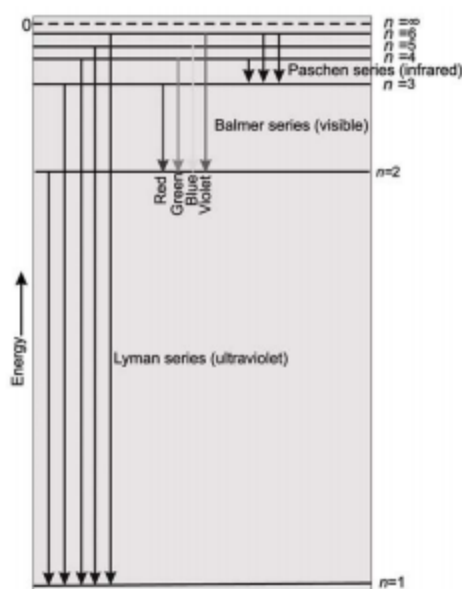
Wavelength increases  $\rightarrow$

cosmic rays |  $\gamma$ -rays |  $\chi$ -rays | uv rays | visible rays | IR rays | microwaves | radiowaves

frequency decreases  $\rightarrow$

**Spectrum of Hydrogen**

Atomic spectrum of hydrogen is obtained by the analysis of the light emitted from the discharge tube containing hydrogen at low pressure using a spectroscope. It consists of six series of lines.



	<u>Series</u>	<u>Region</u>	<u><math>n_1</math></u>	<u><math>n_2</math></u>
1.	Lyman Series	Ultraviolet region	1	2, 3, 4, ..... $\infty$
2.	Balmer Series	Visible region	2	3, 4, 5, ..... $\infty$
3.	Paschen Series	Near Infrared region		3 4, 5, 6 ..... $\infty$
4.	Brackett Series	Infrared region	4	5, 6, 7 ..... $\infty$
5.	Pfund Series	Far Infrared region		5 6, 7, 8 ..... $\infty$
6.	Humphrey Series	Far Infrared region		6 7, 8, 9 ..... $\infty$

The wave number of line in any series,  $\bar{\nu} = R_H \left[ \frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$  - Rydberg's equation.

For other one electron species like,  $\text{He}^+$ ,  $\text{Li}^{2+}$  etc.

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

$$R_H = 1.09678 \times 10^7 \text{ m}^{-1} \quad \text{OR} \quad 1.09678 \times 10^5 \text{ cm}^{-1}$$

#### Bohr theory and Bohr model:

- Electrons revolve around the nucleus in circular orbits.
- Each orbit has fixed amount of energy. So it is called a stationary state
- Only those orbits where angular momentum is an integral multiple of  $\frac{h}{2\pi}$  are allowed ie,  $mvr = \frac{nh}{2\pi}$   
 $n=1, 2, 3, \dots, \infty$ . It is called principal quantum number.
- The energy of electron increases with increasing value of 'n'
- Energy difference between adjacent orbits decreases in going away from the nucleus
- If an electron jumps from higher energy state  $E_2$  to lower energy state  $E_1$ , radiation of a frequency  $\nu$  is emitted. If it moves from  $E_1$  to  $E_2$ , the same frequency is absorbed.  $h\nu = E_2 - E_1$

#### Energy of electron in the $n^{\text{th}}$ orbit:

$$E_n = \frac{-2\pi^2 m e^4 Z^2 k^2}{n^2 h^2} \quad \text{where} \quad k = \frac{1}{4\pi\epsilon_0}$$

$$= \frac{-AZ^2}{n^2} \quad \text{where} \quad A = 2.179 \times 10^{-18} \text{ J atom}^{-1} \quad \text{OR} \quad 1312 \text{ kJmol}^{-1} \quad \text{OR} \quad 13.6 \text{ eV atom}^{-1}$$

$$\text{OR} \quad 2.179 \times 10^{-11} \text{ erg / atom}$$

**Radius of an orbit :**

$$r = \frac{n^2 h^2}{4\pi^2 m e^2 z k} = \frac{n^2 a_0}{z} \text{ where } a_0 \text{ is the radius of the first Bohr orbit in hydrogen atom ie, } 0.529 \text{ \AA}$$

**Velocity of electron in an orbit :**

$$V = \frac{2\pi e^2 z k}{n h} = \frac{2.189 \times 10^6 z}{n} \text{ where } 2.189 \times 10^6 \text{ ms}^{-1} \text{ is the velocity of the electron in the first orbit of H atom}$$

If  $-x$  is the total energy of an electron in a Bohr orbit, its K.E. is  $+x$  and P.E. is  $-2x$

**Merits of Bohr's Atom Model**

1. It could explain the stability of an atom
2. It could explain the atomic spectrum of hydrogen
3. It could calculate the energy of electron and the radius

$$\text{Energy; } E_n = \frac{-2\pi^2 k^2 m e^4 z^2}{n^2 h^2}$$

4. It could calculate the amount of energy emitted when an electron fall from higher energy level to lower energy level

$$\text{ie., } \Delta E = 1312 \left[ \frac{1}{n_1^2} - \frac{1}{n_2^2} \right] \text{ kJ / mole}$$

**Demerits:**

1. It could not explain the fine spectrum of hydrogen
2. It could not explain Zeeman effect and Stark effect.  
Splitting of spectral lines in Magnetic field is called Zeeman effect  
Splitting of spectral lines in Electric field is called Stark effect
3. It could not explain chemical bonding
4. It could not explain De-Broglie's equation (ie. dual nature of matter)
5. It could not explain Heisenberg's un-certainty principle
6. It is applicable to hydrogen like systems only

**Dual Nature of Matter**

Loui's de-Broglie suggested that just as light, all microscopically moving particles such as electrons, protons, atoms, molecules etc, have dual nature. The wave associated with matter is called matter wave and its wavelength can be determined using de-Broglie's equation.

$$\lambda = \frac{h}{mv} \text{ ie } \lambda = \frac{h}{p} \text{ ie } \lambda \propto \frac{1}{p} \text{ also } \lambda = \frac{h}{\sqrt{2mE}}, \text{ where } E \text{ is kinetic energy.}$$

de-Broglie's concept of wave character of electron was experimentally verified by DAVISON and GERMER.

### Heisenberg's Uncertainty Principle

Both the position and momentum of microscopically moving particle cannot be determined accurately and simultaneously.

Mathematically ; it can be expressed as  $\Delta x \cdot \Delta p \geq h/4\pi$ .

$\Delta x \rightarrow$  uncertainty in position

$\Delta p \rightarrow$  uncertainty in momentum

$$\text{Also } \Delta x \cdot \Delta v \geq \frac{h}{4\pi m}, \Delta E \cdot \Delta t \geq \frac{h}{4\pi}; \Delta E = \text{kinetic energy}$$

$\Delta V =$  Unertainty in velocity;  $m =$  mass of the particle

### Quantum Numbers

#### Principal Quantum number (n) - Bohr

$$n = 1, 2, 3, 4, \dots \infty$$

It determines size and energy of an orbital

Each main shell contains n subshells,  $n^2$  orbitals and max.  $2n^2$  electrons

#### Azimuthal Quantum number (l) - Sommerfeld

$$l = 0, 1, 2, \dots (n-1)$$

It determines (i) shape of an orbital

$$(ii) \text{ Orbital angular momentum of electrons as } \sqrt{l(l+1)} \frac{h}{2\pi}$$

$l = 0 \rightarrow$  s subshell

$l = 1 \rightarrow$  p subshell

$l = 2 \rightarrow$  d subshell

$l = 3 \rightarrow$  f subshell

Each subshell contains  $(2l + 1)$  orbitals and maximum  $(4l + 2)$  electrons



### **Magnetic Quantum number (m) - Lande**

$$m = -l, \dots, 0, \dots, +l$$

It determines orientation of an orbital

### **Spin Quantum number (s) - Uhlenbeck and Goudsmit**

The values are  $+\frac{1}{2}$  and  $-\frac{1}{2}$

They show two different directions of spin

S determines spin angular momentum of an electron as  $\sqrt{S(S+1)} \frac{h}{2\pi}$

### **Rules for filling electrons in atoms**

#### **(i) Aufbau Principle**

Electrons occupy the orbitals in the order of increasing energy

In hydrogen like species (one electron system) energy of an orbital increases with increasing n value

In multielectronic atoms

(i) energy of an orbital increases with increasing (n + l) value

(ii) if two orbitals have same (n + l) value, the orbital with lower n value has lower energy

#### **(ii) Pauli's Exclusion Principle**

No two electrons in an atom can have the same set of four quantum numbers

Because of this principle an orbital can contain a maximum of only 2 electrons

### **Hund's rule of Maximum Multiplicity**

In filling degenerate orbitals, the electrons are placed singly with parallel spin before pairing takes place in any one of them

### **Exceptional stability of half filled and fully filled orbitals**

When all the orbitals of a subshell are half filled and fully filled, these configurations have extrastability due to (i) spherical symmetry and (ii) exchange energy

### **Magnetic Properties**

Molecules, atoms or ions containing unpaired electrons have an internal magnetic field due to spin of electrons. Its magnetic moment,  $\mu = \sqrt{n(n+2)}\text{BM}$ . Such substances are feebly attracted by an external magnetic field and are called paramagnetic substances. Substances with only paired electrons have no net spin magnetic field. They are repelled weakly by an external magnetic field and are said to be diamagnetic.



## Wave function $\psi$

$\psi$  of an orbital is a function with different values at different points around the nucleus.  $\psi$  has no physical significance, but according to Max Born  $\psi^2$  at a point is proportional to the probability density at the point or the probability of finding the electron at that point. From the value of  $\psi^2$  at different points within an atom, the region in space around the nucleus where there is maximum probability of finding the electron (orbital) can be found out.

## Radial probability distribution curves :

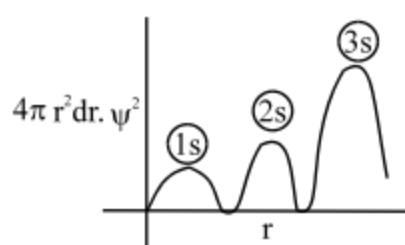
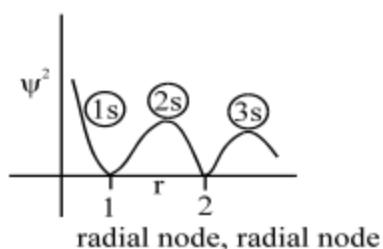
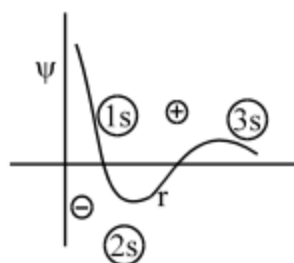
They give the total probability of finding the electron at different distances from the nucleus. Points in these curves where the probability is zero are called nodal points. They correspond to spherical or radial nodes. Number of spherical nodes =  $(n - \ell - 1)$ . These curves give the size of orbitals. Number of maxima =  $(n - \ell)$

## Radial Probability Distribution Curves

$\psi$  = radial wavefunction,  $\cup$

$\psi^2$  radial probability density

$4\pi r^2 dr \psi^2$  - radial probability function



## Angular probability curves :

They give the probability of finding the electron in an orbital at different angles around the nucleus. We get the shapes of orbitals from these curves. Angular nodes are planes or surfaces passing through the nucleus where the probability is zero. Their number is equal to ' $\ell$ '. Total number of spherical and angular nodes =  $(n - 1)$

## Shapes of orbitals :

s orbitals are spherical in shape.

p orbitals are dumbbell shaped.

d orbitals are double dumbbell shaped.

$P_x$  orbital lies along X axis,  $P_y$  along Y axis and  $P_z$  along z axis.  $d_{xy}$  orbitals lie between X and Y axes,  $d_{yz}$  lobes between Y and Z axes,  $d_{xz}$  lobes between X and Z axes and  $d_{x^2-y^2}$  lobes along X and Y axes,  $d_{z^2}$  has two lobes lying along the Z axis surrounded by a collar in the XY plane.

A plane passing through the nucleus where the probability density is zero in an orbital is called nodal plane (angular node). Its number is ' $\ell$ '. Total number of radial and angular nodes =  $n-1$ .

### Differences between orbit and orbital

Orbit	Orbital
1. It is definite circular path around the nucleus where the electrons are revolving	1. It is the region of space around the nucleus where there is maximum probability to find an electron
2. It is obtained from Bohr's theory	2. It is obtained from Heisenberg's uncertainty principle
3. It is 2-dimensional (Planar motion of electrons)	3. It is 3-dimensional (3D motion of electrons)
4. Orbits are circular	4. They have different shapes Eg: S orbital is spherical P orbital is dumb-bell shaped
5. An orbit can accommodate a maximum of $2n^2$ electrons $n$ = principal quantum number	5. An orbital can accommodate only 2 electrons

## PART-I (JEE MAIN)

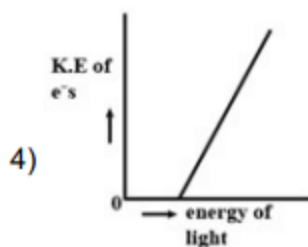
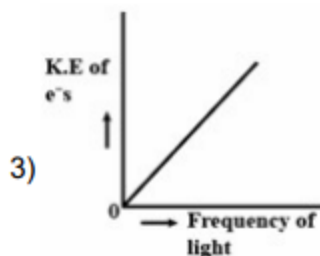
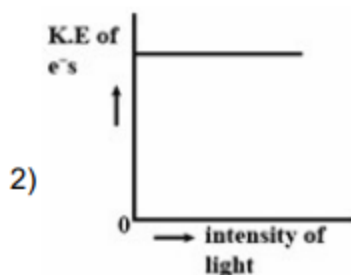
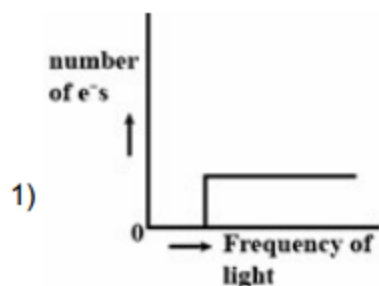
### SECTION-I- Straight objective type questions

- Atomic number and mass number of an element are 11 and 23 respectively. The nucleus of an atom of this element contains
  - 11 protons, 12 neutrons and 11 electrons
  - 12 protons and 11 neutrons
  - 11 protons and 12 neutrons
  - 12 protons, 11 neutrons and 12 electrons
- The increasing order of  $e/m$  ratio for electron (e), proton (p), neutron (n) and alpha particle ( $\alpha$ ) is
  - 1) e, p, n,  $\alpha$
  - 2) n, p, e,  $\alpha$
  - 3) n, p,  $\alpha$ , e
  - 4) n,  $\alpha$ , p, e

3. The energy of a radiation of wavelength  $8000 \text{ \AA}$  is  $E_1$  and energy of a radiation of wavelength  $16000 \text{ \AA}$  is  $E_2$ . What is the relation between  $E_1$  and  $E_2$ ?

- 1)  $E_1 = 6E_2$                       2)  $E_1 = 2E_2$                       3)  $E_1 = 4E_2$                       4)  $E_1 = \frac{1}{2}E_2$

4. Which of the graphs shown below does not represent the relationship between incident light and the electron ejected from metal surface?



5. **Assertion:** The transition of an electron in a hydrogenic species from  $n = 3$  state to  $n = 2$  state will emit a greater energy than the transition from  $n = 4$  state to  $n = 3$  state.

**Reason:** The states  $n = 3$  and  $n = 2$  are lower in energy than the state  $n = 4$

In light of the above statements choose the correct option

- 1) Both assertion and reason are true and the reason is the correct explanation of the assertion.  
 2) Both assertion and reason are true but reason is not the correct explanation of the assertion.  
 3) Assertion is true but reason is false.  
 4) Assertion is false but reason is true.
6. What is the ratio of maximum and minimum wavelengths associated with the Balmer series of hydrogen spectrum?

- 1)  $\frac{4}{3}$                       2)  $\frac{3}{4}$                       3)  $\frac{9}{5}$                       4)  $\frac{5}{9}$

7. In a sample of hydrogen atoms, electron jumps from 10<sup>th</sup> excited state to the ground state. If x is the number of different uv radiations, y is the number of different visible radiations and z is the number of different infrared radiations obtained from the sample, then the value of z-(x + y) is (Assume all the Balmer lines fall in the visible region of electromagnetic spectrum)
- 1) 17                      2) 18                      3) 19                      4) 36
8. The radius of second Bohr orbit in He<sup>+</sup> is 'b'. Then the radius of third Bohr orbit in Be<sup>3+</sup> will be
- 1)  $\frac{3b}{16}$                       2)  $\frac{9b}{8}$                       3)  $\frac{16b}{3}$                       4)  $\frac{8b}{9}$
9. The de Broglie wave length associated with an electron in the ground state of Li<sup>2+</sup> is  $x\pi a_0$ , where  $a_0$  is the radius of first orbit of hydrogen atom. The value of x is
- 1)  $\frac{2}{3}$                       2)  $\frac{3}{4}$                       3)  $\frac{3}{2}$                       4) 6
10. **Assertion:** The position of an electron can be determined exactly with the help of an electron microscope.  
**Reason:** The product of uncertainty in the measurement of its momentum and the uncertainty in the measurement of the position cannot be less than a finite limit.  
 In light of the above statements choose the correct option
- 1) Both assertion and reason are true and the reason is the correct explanation of the assertion.  
 2) Both assertion and reason are true but reason is not the correct explanation of the assertion.  
 3) Assertion is true but reason is false.  
 4) Assertion is false but reason is true.
11. The uncertainty in the position of an electron (mass =  $9.1 \times 10^{-28}$  g) moving with a velocity of  $3.0 \times 10^4 \text{ cm s}^{-1}$  accurate upto 0.001% will be (Use  $\frac{h}{4\pi}$  in the uncertainty expression, where  $h = 6.626 \times 10^{-27} \text{ erg-s}$ )
- 1) 1.92 cm                      2) 7.68 cm                      3) 5.76 cm                      4) 3.84 cm
12. **Match List I with List II**
- | List - I   | List - II |
|--|-----------|
| (A) Number of radial node(s) of 5s orbital                         | (P) 1     |
| (B) Number of angular node(s) of $3d_{yz}$ orbital                 | (Q) 4     |
| (C) Sum of angular node(s) and radial node(s) of $4d_{xy}$ orbital | (R) 2     |
| (D) Number of radial node(s) of 3p orbital                         | (S) 3     |
- 1) A - Q, B - R, C - P, D - S  
 2) A - R, B - Q, C - P, D - S  
 3) A - Q, B - R, C - S, D - P  
 4) A - R, B - Q, C - S, D - P

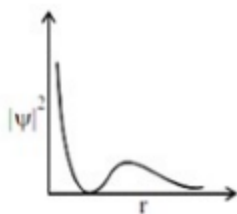
13. Which of the following sets of quantum numbers is correct for the 19<sup>th</sup> electron of chromium?

	n	$\ell$	m	s
1)	3	0	0	$\frac{1}{2}$
2)	3	2	-2	$\frac{1}{2}$
3)	4	0	0	$\frac{1}{2}$
4)	4	1	-1	$\frac{1}{2}$

14. Which of the following orbitals has zero probability of finding the electron in the yz plane?

1)  $p_x$                                   2)  $p_y$                                   3)  $p_z$                                   4)  $d_{yz}$

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



1) 3s orbital                                  2) 1s orbital                                  3) 2p orbital                                  4) 2s orbital

16. Assertion: Energy of 2s orbital of lithium atom is greater than that of 2s orbital of sodium

Reason: Energy of orbitals in the same subshell decreases with increase in atomic number.

In light of the above statements choose the correct option

- 1) Both assertion and reason are true and the reason is the correct explanation of the assertion.
- 2) Both assertion and reason are true but reason is not the correct explanation of the assertion.
- 3) Assertion is true but reason is false.
- 4) Assertion is false but reason is true.

**SECTION-II - Numerical Type Questions**

17. Values of work function (
- $W_0$
- ) for a few metals are listed below

Metal	$W_0/\text{eV}$
Li	2.42
Na	2.3
Cu	4.8
Ag	4.3
K	2.25
Mg	3.7

How many of the above metals can give photocurrent if irradiated using a light of frequency  $5.8 \times 10^{14}$  Hz? [Use  $h = 6.6 \times 10^{-34}$  Js;  $1 \text{ J} = 6.24 \times 10^{18} \text{ eV}$ ]

18. The energy of an electron in the first Bohr orbit of hydrogen atom is  $-13.6 \text{ eV}$ . The energy of an electron in the first excited state of  $\text{Be}^{3+}$  is  $\dots\dots\dots \text{eV}$
19. The number of radial nodes and angular nodes of an atomic orbital are two and zero respectively. The  $n + l$  value for the orbital is  $\dots\dots\dots$
20. The number of orbitals associated with quantum numbers  $n = 5$ ,  $m_s = +\frac{1}{2}$  is  $\dots\dots\dots$

**PART-II (JEE ADVANCED)****Section-III - Only one option correct type**

21. For a particular electronic transition in  $\text{He}^+$ , the sum of quantum numbers corresponding to the higher orbit and the lower orbit and the difference between squares of quantum numbers for the same two orbits are 4 and 8 respectively. The wavelength of the emitted photon in the above transition is ( $R_H$  is the Rydberg's constant in  $\text{cm}^{-1}$ )
- A)  $\frac{32}{9}R_H$       B)  $\frac{9}{32}R_H$       C)  $\frac{9}{32R_H}$       D)  $\frac{32}{9R_H}$
22. Radius of third orbit of  $\text{Li}^{+2}$  ion is 'X' cm. The de-Broglie wavelength of electron in the first orbit in the same species is
- A)  $\frac{2\pi X}{3} \text{ cm}$       B)  $6\pi X \text{ cm}$       C)  $3\pi X \text{ cm}$       D)  $\frac{2\pi X}{6} \text{ cm}$
23. If a radiation of wavelength  $4000 \text{ \AA}$  is used to break the iodine molecule, then the percentage of energy converted into kinetic energy of iodine atoms is (Given: bond dissociation energy of iodine molecule is  $246.5 \text{ kJ/mol}$ )
- A) 8%      B) 12%      C) 17%      D) 25%



24. If the energy of H-atom in the ground state is '-E', the velocity ( $v$ ) of photoelectron emitted when a photon having energy ' $E_p$ ' strikes a stationary  $\text{Li}^{2+}$  ion in the ground state is given by  
( $m$  = mass of electron)

A)  $v = \sqrt{\frac{2(E_p - E)}{m}}$       B)  $v = \sqrt{\frac{2(E_p + 9E)}{m}}$       C)  $v = \sqrt{\frac{2(E_p - 9E)}{m}}$       D)  $v = \sqrt{\frac{2(E_p - 3E)}{m}}$

25. An electron in a single electron atomic species jumps in such a way that its kinetic energy changes from  $x$  to  $x/4$ . The change in potential energy will be

A)  $+\frac{3}{2}x$       B)  $-\frac{3}{8}x$       C)  $+\frac{3}{4}x$       D)  $-\frac{3}{4}x$

26. The angular momentum of an electron in a Bohr's orbit of  $\text{He}^+$  is  $3.1652 \times 10^{-34} \text{ kg m}^2 \text{ sec}^{-1}$ . What is the wave number in terms of Rydberg constant ( $R$ ) of the spectral line emitted when an electron falls from this level to the first excited state? [Use  $h = 6.626 \times 10^{-34} \text{ Js}$ ]

A)  $3R$       B)  $\frac{5R}{9}$       C)  $\frac{3R}{4}$       D)  $\frac{4R}{3}$

27. The deBroglie wavelength ( $\lambda$ ) associated with a photoelectron varies with the frequency ( $\nu$ ) of the incident radiation as, [ $\nu_0$  is Threshold frequency]

A)  $\lambda \propto \frac{1}{(\nu - \nu_0)^{3/2}}$       B)  $\lambda \propto \frac{1}{(\nu - \nu_0)^{1/2}}$       C)  $\lambda \propto \frac{1}{(\nu - \nu_0)^{1/4}}$       D)  $\lambda \propto \frac{1}{(\nu - \nu_0)}$

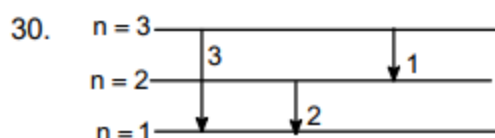
#### **Section IV - One or more option correct type**

28. Which of the following statements about an electron occupying the 1s orbital in a hydrogen atom is/are correct? (The Bohr radius is represented by  $a_0$ )

- A) The electron can be found at a distance of  $2a_0$  from the nucleus  
B) The probability density of finding the electron is maximum at the nucleus.  
C) The magnitude of potential energy is double that of its kinetic energy on an average.  
D) The total energy of the electron is maximum when it is at a distance of  $a_0$  from the nucleus.



29. Which of the following statements is/are true regarding the interpretation of the atomic orbitals?
- (A) An electron in an orbital of high angular momentum stays away from the nucleus than an electron in an orbital of lower angular momentum.
- (B) For a given value of the principal quantum number, the size of the orbital is inversely proportional to the azimuthal quantum number.
- (C) The radial distribution function of all orbitals are zero at the nucleus
- (D) The angular wave function of any s orbital is zero



For the above transitions in hydrogen like atoms, select the correct relation(s). ( $\nu$  and  $\lambda$  are frequency and wavelength of the transition, respectively)

- A)  $\nu_3 = \nu_1 + \nu_2$       B)  $\nu_3 = \frac{\nu_1 \nu_2}{\nu_1 + \nu_2}$       C)  $\lambda_3 = \lambda_1 + \lambda_2$       D)  $\lambda_3 = \frac{\lambda_1 \lambda_2}{\lambda_1 + \lambda_2}$
31. Let  $r$ ,  $v$  and  $E$  be the radius of the orbit, speed of the electron and the kinetic energy of the electron, respectively in a hydrogen-like species X. Which of the following quantities is/are proportional to the quantum number 'n'?
- A)  $rE$       B)  $vr$       C)  $v/E$       D)  $r/E$

### Section V - Numerical type questions

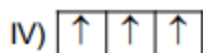
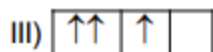
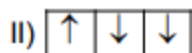
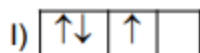
32. A hydrogen-like species (atomic number  $Z$ ) is present in a higher excited state of quantum number 'n'. The electron in this excited atom can make a transition to the first excited state by successive emission of two photons of energies 10.20 eV and 17.0 eV respectively. Alternatively, the atom from the same higher excited state can de-excite to the second excited state by successive emission of two photons of energy 4.25 eV and 5.95 eV respectively. Determine the value of  $Z$ .

33. The wave function of 2s orbital is given by,  $\psi_{2s} = \frac{1}{4\sqrt{2\pi}} \left( \frac{1}{a_0} \right)^{\frac{3}{2}} \left( 2 - \frac{r_0}{a_0} \right) e^{-\frac{r_0}{a_0}}$ . If  $a_0$  = Bohr radius and  $r_0$  = distance of radial node from the nucleus, then find the value of  $\frac{r_0}{a_0}$

**Section-VI - Matrix match type**

34. Match the following

Column-I (Electronic configuration)



A) I  $\rightarrow$  PQ; II  $\rightarrow$  P; III  $\rightarrow$  Q; IV  $\rightarrow$  R

C) I  $\rightarrow$  PQ; II  $\rightarrow$  Q; III  $\rightarrow$  Q; IV  $\rightarrow$  R

Column-II (Feature)

P) Violates Hund's rule

Q) Violates Pauli principle

R) Obeys both Hund's rule and Pauli principle

B) I  $\rightarrow$  P; II  $\rightarrow$  P; III  $\rightarrow$  Q; IV  $\rightarrow$  R

D) I  $\rightarrow$  P; II  $\rightarrow$  Q; III  $\rightarrow$  R; IV  $\rightarrow$  R

35. Match the following

Column-I (Quantum number)

I) Principal quantum number

II) Orbital angular momentum quantum number

III) Magnetic quantum number

IV) Electron spin quantum number

A) I  $\rightarrow$  S; II  $\rightarrow$  Q; III  $\rightarrow$  R; IV  $\rightarrow$  R

C) I  $\rightarrow$  S; II  $\rightarrow$  P; III  $\rightarrow$  Q; IV  $\rightarrow$  R

Column-II (Significance)

P) Shape of orbital

Q) Orientation of orbital

R) Spin state of electron

S) Size of orbital

B) I  $\rightarrow$  Q; II  $\rightarrow$  P; III  $\rightarrow$  S; IV  $\rightarrow$  R

D) I  $\rightarrow$  Q; II  $\rightarrow$  R; III  $\rightarrow$  S; IV  $\rightarrow$  R