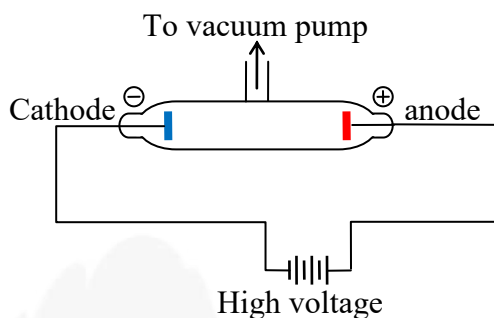


1. INTRODUCTION

1.1 CATHODE RAYS (Discovery of e^-)

In 1859, Julius Plucker started the study of conduction of electricity through gases at low pressure in a discharge tube. When a high voltage of the order 10,000 volts or more was applied across the electrodes, some sort of invisible rays moved from the negative electrode to the positive electrode. Since the negative electrode is referred to as cathode, these rays were called cathode rays.

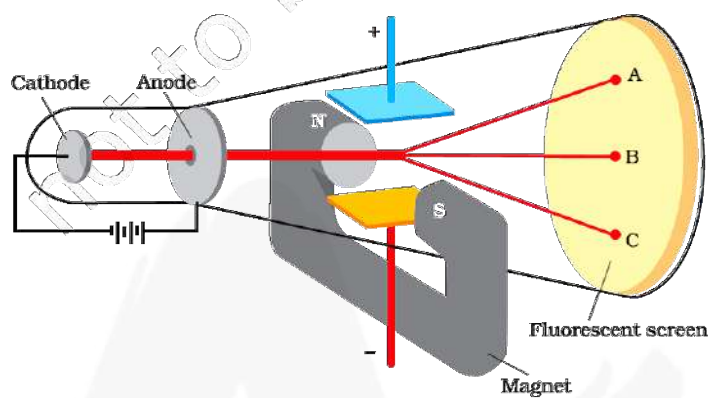
◆ Properties of Cathode rays:

- (i) Path of travelling is straight with a very high velocity as it produces shadow of an object placed in their path.
- (ii) Cathode rays produce mechanical effects. If small light paddle wheel is placed between the electrodes, it rotates. This indicates that the cathode rays consist of material particles.
- (iii) When electric and magnetic fields are applied, the rays are deflected thus establishing that they consist of charged particles. The direction of deflection showed that cathode rays consist of negatively charged particles called **electrons**. Electrons were discovered by J.J. Thomson.
- (iv) They produce a green glow when strike the glass wall beyond the anode. Light is emitted when they strike the zinc sulphide screen.
- (v) Cathode rays penetrate through thin sheets of aluminium and other metals, affect the photographic plates and produce heating effect when they collide with a metal objective.
- (vii) Specific charge i.e. charge/mass is same (1.76×10^{11} C/kg) for all cathode rays irrespective of the gas used in the tube or the material of cathode. Thus, electrons were considered fundamental particles of matter.
- (viii) Cathode rays can ionize the gases through which they pass.
- (ix) The nature of cathode rays is independent of
 - (a) The nature of cathode and
 - (b) The gas in discharge tube.

1.2 MEASUREMENT OF e/m FOR ELECTRON:

In 1897, J.J. Thomson determined the e/m value (charge/mass) of the electron by studying the deflection of cathode rays in electric & magnetic fields.

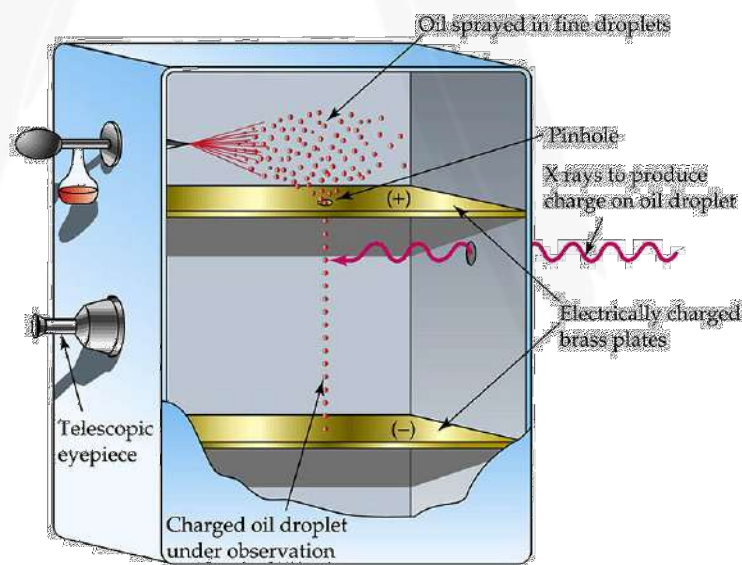
The value of e/m has been found to be -1.7588×10^8 coulomb/g.



- ◆ By performing a series of experiments, Thomson proved that whatever gas be taken in the discharge tube and whatever be the material of the electrodes the value of e/m is always the same.
- ◆ Electrons are thus common universal constituents of all atoms.

1.3 DETERMINATION OF THE CHARGE ON AN ELECTRON:

The absolute value of the charge on an e^- was measured by R.A. Millikan in 1909 by the Millikan's oil drop experiment.



- ◆ The apparatus used by him is shown in figure.
- ◆ An oil droplet falls through a hole in the upper plate. The air between the plates is then exposed to X-rays which eject electrons from air molecules. Some of these e^- are

captured by the oil droplet and it acquires a negative charge. The metal plates were given an electric charge, and as the electric field between the plates was increased, it was possible to make some of the drops travel upwards at the same speed as they were previously falling.

By measuring the speed, and knowing things like the strength of the field and the density of the oil, radius of oil drops, Millikan was able to calculate the magnitude of the charge on the oil drops. He found that the smallest charge to be found on them was approximately 1.59×10^{-19} C. This was recognized as the charge on an e^- . The modern value is 1.602×10^{-19} C.

1.4 MASS OF THE ELECTRON :

Mass of the e^- can be calculate from the value of e/m and the value of e

$$m = \frac{e}{e/m} = \frac{-1.602 \times 10^{-19}}{-1.7588 \times 10^8} = 9.1096 \times 10^{-28} \text{g} \quad \text{or} \quad = 9.1096 \times 10^{-31} \text{kg}$$

This is termed as the mass of the electron i.e. mass of electron when moving with low speed. The mass of a moving e^- may be calculate by applying the following formula.

$$\text{Mass of moving } e^- = \frac{\text{rest mass of } e^-}{\sqrt{1 - (v/c)^2}}$$

Where v is the velocity of the e^- and c is the velocity of light

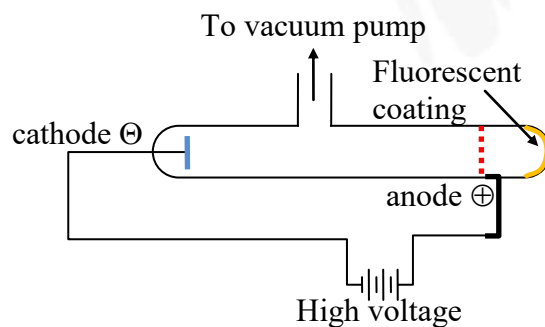
When $v = c \Rightarrow \text{mass of } e^- = \infty$

$v = c \Rightarrow \text{mass of } e^- = \text{imaginary}$

1.5 POSITIVE RAYS - (DISCOVERY OF PROTON) :

Goldstein (1886) repeated the cathode ray experiment with a discharge tube filled with a perforated cathode and found that new type of rays came out through the hole in the cathode.

When this experiment is conducted, a faint red glow is observed on the wall behind the cathode. These rays are called anode rays.



- (i) Anode rays travel along straight paths and hence they cast shadows of object placed in their path.

- (ii) They rotate a light paddle wheel placed in their path. This shows that anode rays are made up of material particles.
- (iii) They are deflected in magnetic field as well as towards the negative plate of an electric field. This shows that these rays are positively charged.
- (iv) For different gases used in the discharge tube, the species charge of the positive particles constituting the positive rays is different. When hydrogen gas is taken in the discharge tube, the q/m value obtained for the positive rays is found to be maximum. Since the value of charge (q) on the positive particle obtained from different gases is the same, the value of m must be minimum for the positive particles obtained from hydrogen gas. Thus, the positive particle obtained from hydrogen gas is the lightest among all the positive particles obtained from different gases. This particle is called the proton (H^+) and is also considered a fundamental particle of matter.

Thus

$$\text{Charge on proton} = +1.602 \times 10^{-19} \text{ coulomb}$$

- ◆ The mass of the proton, thus can be calculated.

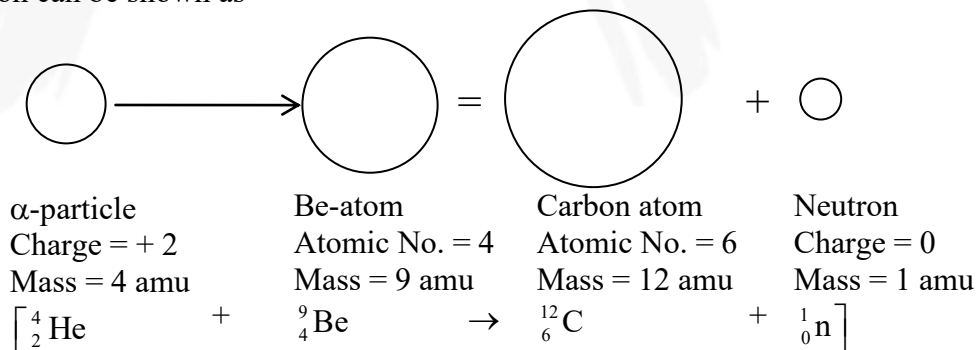
$$\text{Mass of the proton} = \frac{e}{e/m} = \frac{1.602 \times 10^{-19}}{9.597 \times 10^4} = 1.672 \times 10^{-24} \text{ g} = 1.672 \times 10^{-27} \text{ kg}$$

$$\text{Mass of proton in amu} = \frac{1.672 \times 10^{-24}}{1.66 \times 10^{-24}} = 1.00757 \text{ amu.}$$

1.6 NEUTRON

In 1920, **Rutherford** suggested that in an atom, there must be present at least a third type of fundamental particles which should be electrically neutral and possess mass nearly equal to that of proton. He proposed the name for such fundamental particles as neutron.

In 1932, **Chadwick** bombarded beryllium with a stream of α -particles. He observed that penetrating radiations were produced which were not affected by electric & magnetic fields. These radiations consisted of neutral particles, which were called neutrons. The nuclear reaction can be shown as



Thus a neutron is a sub atomic particle which has a mass $1.675 \times 10^{-24} \text{ g}$ approximately 1amu, or nearly equal to the mass of proton or hydrogen atom and carrying no electrical charge.

- ◆ The e/m value of a neutron is zero.
- ◆ Atom is a Greek word and its meaning Indivisible i.e. an ultimate particles which cannot be further subdivided.
- ◆ Atom is actually made of 3 fundamental particles :
 1. Electron
 2. Proton
 3. Neutron

Fundamental Particle	Discovered By	Charge	Mass	(Specific Charge)
Electron (e^-)	J.J. Thomson	-1.6×10^{-19} coulomb -4.8×10^{-10} esu	9.1×10^{-31} kg 0.000548 amu	1.76×10^8 C/g
Proton (P) (Ionized H atom, H^+)	Goldstein	$+1.6 \times 10^{-19}$ coulomb $+4.8 \times 10^{-10}$ esu	1.672×10^{-27} kg 1.00757 amu	9.58×10^4 C/g
Neutron (${}_0n^1$)	James Chadwick	0	1.672×10^{-27} kg 1.00893 amu	0

❑ **IMPORTANT POINT :**

1. esu = electrostatic unit
 $(1 \text{ cb} = 3 \times 10^9 \text{ esu})$
 amu = atomic mass unit
 $1 \text{ amu} = 1.6 \times 10^{-24} \text{ g} = 1.6 \times 10^{-27} \text{ kg}$
2. Order of Mass
 $m_{e^-} < m_p < m_n$

◆ **Order of Specific Charge**

$$\left(\frac{e}{m} \right)_n < (e/m)_p < (e/m)_{e^-}$$

$$\left(\frac{\text{mass of proton}}{\text{mass of electron}} \right) \frac{m_p}{m_{e^-}} = 1837$$

2. ATOMIC MODELS/THEORIES:**2.1 DALTON'S ATOMIC THEORY :**

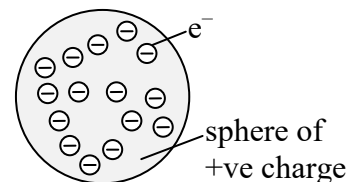
The atomic theory of matter was first proposed on a firm scientific basis by John Dalton, a British school teacher in 1808. His theory, called Dalton's atomic theory, regarded the atom as the ultimate particle of matter. Dalton's atomic theory was able to explain the law of conservation of mass, law of constant composition and law of multiple proportion very successfully. However, it failed to explain the results of many experiments, for example, it was known that substances like glass or ebonite when rubbed with silk or fur get electrically charged.

Postulates of Dalton's hypothesis are as follows :

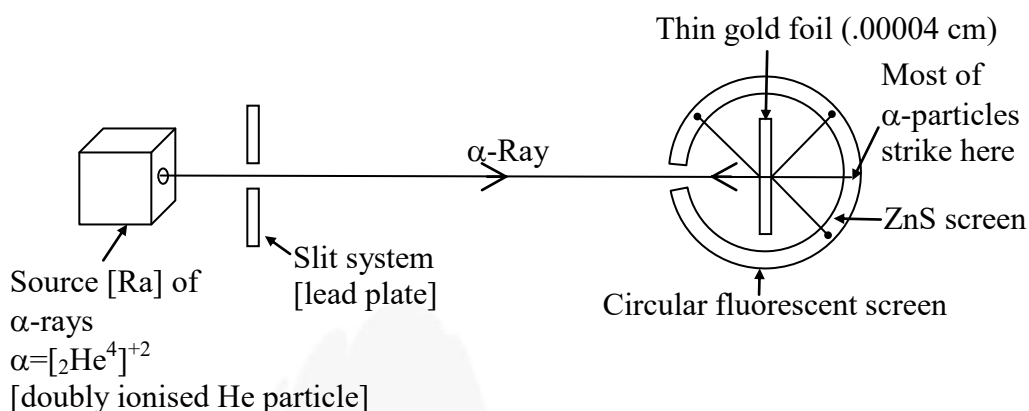
- (i) Each element is composed of extremely small particles called atoms which can take part in chemical combination.
- (ii) All atoms of a given element are identical i.e., atoms of a particular element are all alike but differ from atoms of other elements.
- (iii) Atoms of different elements possess different properties (including different masses).
- (iv) Atoms are indestructible i.e., atoms are neither created nor destroyed in chemical reactions.
- (v) Atoms of elements combine to form molecules and compounds are formed when atoms of more than one element combine.
- (vi) In a given compound, the relative number and kind of atoms is constant.

2.2 THOMSON'S MODEL OF ATOM [1904]

- ◆ Thomson was the first to propose a detailed model of the atom.
- ◆ Thomson proposed that an atom consists of a uniform sphere of positive charge in which the electrons are present at some places.
- ◆ This model of atom is known as 'Plum-Pudding model'.

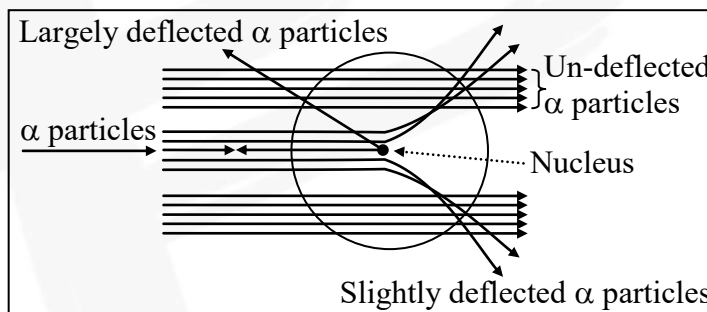
**2.2.1 DRAWBACKS :**

- ◆ An important drawback of this model is that the mass of the atoms is considered to be evenly spread over that atom.
- ◆ It is a static model. It does not reflect the movement of electron.

2.3 RUTHERFORD'S α - SCATTERING EXPERIMENT α - scattering experiment

2.3.1 Rutherford observed that :

- (i) Most of the α -particles (nearly 99.9%) went straight without suffering any deflection.
- (ii) A few of them got deflected through small angles.
- (iii) A very few α -particles (about one in 20,000) did not pass through the foil at all but suffered large deflections (more than 90°) or even come back in the direction from which they have come i.e. a deflection of 180° .



2.3.2 Following conclusions were drawn from the above observations :

- (1) Since most of the α -particle went straight through the metal foil undeflected, it means that there must be very large empty space within the atom.
- (2) Since few of the α -particles were deflected from their original path through moderate angles; it was concluded that whole of the positive charge is concentrated and the space occupied by this positive charge is very small in the atom.
 - ◆ Whenever α -particles come closer to this point, they suffer a force of repulsion and deviate from their paths.
 - ◆ The positively charged heavy mass which occupies only a small volume in an atom is called nucleus. It is supposed to be present at the centre of the atom.
- (3) A very few of the α -particles suffered strong deflections or even returned on their path indicating that the nucleus is rigid and α -particles recoil due to direct collision with the heavy positively charged mass.

- (4) The relation between number of deflected particles and deflection angle θ is

$$\mu \propto \frac{1}{\sin^4 \frac{\theta}{2}} \quad [\theta \text{ increases } \mu \text{ decreases}]$$

where μ = deflected particles θ = deflection angle

- ◆ As atomic number increases, the number of protons increases which increases the repulsion and so deflection angle θ increases.

2.3.3 APPLICATIONS OF RUTHERFORD MODEL

On the basis of scattering experiments, Rutherford proposed the model of an atom, which is known as nuclear atomic model. According to this model -

- An atom consists of a heavy positively charged nucleus where all the protons are present.
- The volume of the nucleus is very small and is only a minute fraction of the total volume of the atom.

Nucleus has a radius of the order of 10^{-13} cm and the atom has a radius of the order of 10^{-8} cm

$$\frac{r_A}{r_N} = \frac{\text{radius of the atom}}{\text{radius of the nucleus}} = \frac{10^{-8}}{10^{-13}} = 10^5, \quad r_A = 10^5 r_N$$

Thus radius (size) of the atom is 10^5 times the radius of the nucleus.

- ◆ The radius of a nucleus is proportional to the cube root of the **number** of nucleons within it.

$$R \propto A^{1/3} \Rightarrow R = R_0 A^{1/3} \text{ cm}$$

Where $R_0 = 1.33 \times 10^{-13}$ (a constant) and, A = mass number ($p + n$)

R = radius of the nucleus.

$$R = 1.33 \times 10^{-13} A^{1/3} \text{ cm}$$

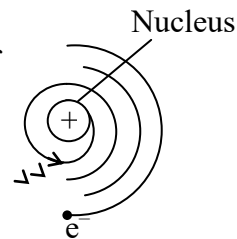
- There is an empty space around the nucleus called extra nuclear part. In this part electrons are present. The **number** of electrons in an atom is always equal to **number** of protons present in the nucleus. As the nuclear part of atom is responsible for the mass of the atom, the extra nuclear part is responsible for its volume. The volume of the atom is about 10^{15} times the volume of the nucleus.

$$\frac{\text{vol. of the atom}}{\text{vol. of the nucleus}} = \frac{\left(\frac{4}{3}\pi r_A^3\right)}{\left(\frac{4}{3}\pi r_N^3\right)} = \frac{(10^{-8})^3}{(10^{-13})^3} = 10^{15}$$

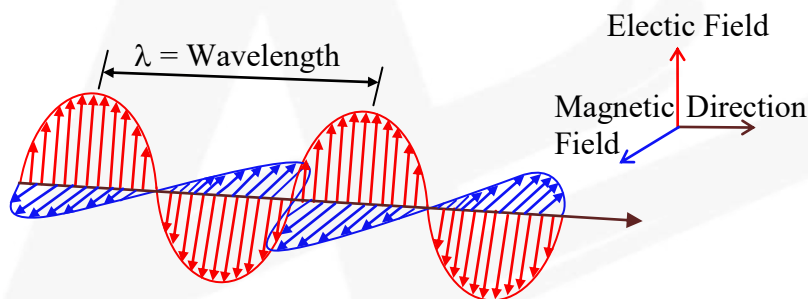
- Electrons revolve round the nucleus in closed orbits with high speeds.
- ◆ This model was similar to the solar system, the nucleus representing the sun and revolving electrons as planets.

2.3.4 Drawbacks of Rutherford's atomic model :

- (1) This theory could not explain the stability of an atom. According to Maxwell electron loses its energy continuously in the form of electromagnetic radiations. As a result of this, the e^- should lose energy at every turn and move closer and closer to the nucleus following a spiral path. The ultimate result will be that it will fall into the nucleus, thereby making the atom unstable.
- (2) If the electrons lose energy continuously, the observed spectrum should be continuous but the actual observed spectrum consists of well defined lines of definite frequencies (discontinuous). Hence, the loss of energy by electron is not continuous in an atom.



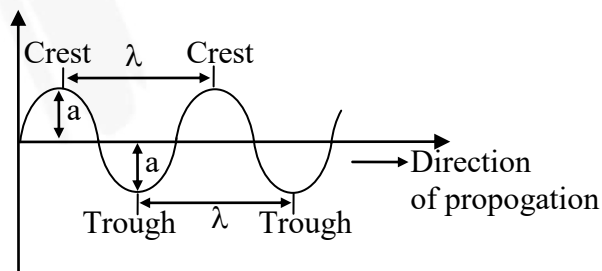
□. Electromagnetic waves (EM waves) or Radiant Energy/Electromagnetic radiation :



- ◆ It is the energy transmitted from one body to another in the form of waves and these waves travel in the space with the same speed as light (3×10^8 m/s) and these waves are known as Electromagnetic waves or radiant energy.
- ◆ The radiant Energy does not need any medium for propagation.

Ex: Radio waves, micro waves, infra red rays, visible rays, ultraviolet rays, x-rays, gamma rays and cosmic rays.

A wave is characterized by following six characteristics. The upper most point of the wave is called crest and the lower most point is called trough. Some of the terms employed in dealing with the waves are described below.

I. Wavelength (λ) :

It is defined as the distance between two nearest crest or nearest trough.

It is measured in terms of \AA (Angstrom), pm (Pico-meter), nm (nanometer), cm (centimeter), m (meter)

$$1\text{\AA} = 10^{-10} \text{ m}, 1 \text{ pm} = 10^{-12} \text{ m}, 1 \text{ nm} = 10^{-9} \text{ m}, 1 \text{ cm} = 10^{-2} \text{ m}$$

II. Frequency (ν) :

Frequency of a wave is defined as the number of waves which pass through a point in 1 sec.

It is measured in terms of Hertz (Hz), sec^{-1} , or cycle per second (cps)

$$1 \text{ Hertz} = 1 \text{ sec}^{-1} = 1 \text{ cps.}$$

III. Time period (T) : Time taken by a wave to pass through one point.

$$T = \frac{1}{\nu} \text{ sec.}$$

IV. Velocity (c) :

Velocity of a wave is defined as distance covered by a wave in 1 sec.

$$C = \lambda / T = \nu \Rightarrow \nu = C / \lambda$$

i.e. frequency is inversely proportional to

V. Wave number ($\bar{\nu}$) : It is the reciprocal of the wave length that is number of waves present

in 1cm

$$1 \text{ m} = 100 \text{ cm}$$

$$\bar{\nu} = \frac{1}{\lambda}$$

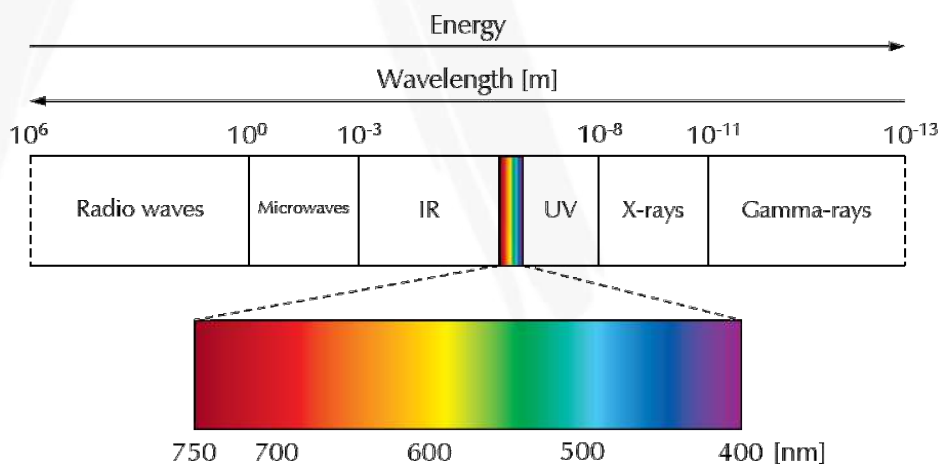
$$\frac{1}{\text{cm}} = \frac{100}{\text{m}}$$

$$(1 \text{ cm}^{-1} = 100 \text{ m}^{-1})$$

◆ It is measured in terms of cm^{-1} , m^{-1} etc,

VI. Amplitude (a)

The amplitude of a wave is defined as the height of crest or depth of trough.



Ex.1 The vividh Bharti station of All India Radio broadcast on a frequency of 1368 Kilo Hertz. Calculate the wave length of the Electromagnetic waves emitted by the transmitter.

Ans. 219.3 m

Sol. As we know velocity of light (C)

$$C = 3 \times 10^8 \text{ m/sec.}$$

Given ν (frequency) = 1368 kHz = $1368 \times 10^3 \text{ sec}^{-1}$

$$\therefore \lambda = \frac{c}{\nu} \quad \therefore \lambda = \frac{3 \times 10^8 \text{ m sec}^{-1}}{1368 \times 10^3 \text{ sec}^{-1}} \Rightarrow \lambda = 219.3 \text{ m}$$

Ex.2 Calculate $\bar{\nu}$ in cm^{-1} and ν of yellow radiation have wavelength of 5800 Å.

Ans. $5.1 \times 10^{14} \text{ sec}^{-1}$

Sol. As we known $\bar{\nu} = \frac{1}{\lambda}$

$$\begin{aligned} \bar{\nu} &= \frac{1}{5800 \text{ Å}} = \frac{1}{5800 \times 10^{-8} \text{ cm}} \quad \{\because 1 \text{ Å} = 10^{-8} \text{ cm}\} \\ &= 17241.4 \text{ cm}^{-1} \end{aligned}$$

$$\begin{aligned} \nu &= c\bar{\nu} \\ &= 3 \times 10^{10} \text{ cm sec}^{-1} \times 1.7 \times 10^4 \text{ cm}^{-1} \\ &= 3 \times 1.7 \times 10^{14} \\ &= 5.1 \times 10^{14} \text{ sec}^{-1} \end{aligned}$$

Ex.3 How long would it take a radio wave of frequency $6 \times 10^3 \text{ sec}^{-1}$ to travel from mars to the earth, a distance of $8 \times 10^7 \text{ km}$?

Ans. $2.66 \times 10^2 \text{ sec}$.

Sol. Distance to be travelled from mars to earth

$$= 8 \times 10^7 \text{ km} = 8 \times 10^{10} \text{ m}$$

\therefore Velocity of EM waves

$$= 3 \times 10^8 \text{ m/sec}$$

$$\therefore \text{Time} = \frac{\text{Distance}}{\text{Velocity}} = \frac{8 \times 10^{10} \text{ m}}{3 \times 10^8 \text{ m/sec}^{-1}} = 2.66 \times 10^2 \text{ sec}.$$

Ex.4 What will be the frequency of photon of wavelength 2225 Å traveling in vacuum ?

Ans. $1.349 \times 10^{15} \text{ sec}^{-1}$

Sol. Velocity of light in vacuum = $3 \times 10^8 \text{ m sec}^{-1}$

$$\text{Wavelength} = 2225 \times 10^{-10} \text{ meter}$$

$$\begin{aligned} \text{Frequency} &= \frac{\text{Velocity}}{\text{Wavelength}} = \frac{3 \times 10^8 \text{ meter/sec}}{2225 \times 10^{-10} \text{ meter}} = \frac{3000}{2225} \times 10^{15} \text{ sec}^{-1} \\ &= 1.349 \times 10^{15} \text{ sec}^{-1} \end{aligned}$$

DO YOURSELF-1

- The ratio of specific charge (e/m) of a proton to that of an α -particle is :
(A) 1 : 4 (B) 1 : 2 (C) 1 : 1/4 (D) 2 : 1
- Atomic radius is of the order of 10^{-8} cm and nuclear radius is of the order of 10^{-13} cm. The fraction of atom occupied by nucleus is :
(A) 10^{-5} (B) 10^5 (C) 10^{-15} (D) None of these
- | | Column-I | Column-II |
|-----|-------------|--|
| (A) | Frequency | (p) length of one complete wave per time period |
| (B) | Wavelength | (q) Number of waves passing through a point in one second |
| (C) | Time period | (r) length of one complete wave |
| (D) | Speed | (s) Time taken for one complete wave to pass through a point. |
- For a broadcasted electromagnetic wave having frequency of 1200 KHz, calculate number of waves that will be formed in 1 km distance (wave number per km).
- Visible spectrum contains light of following colours "Violet - Indigo - Blue - Green - Yellow - Orange - Red" (VIBGYOR).
It's frequency ranges from violet (7.5×10^{14} Hz) to red (4×10^{14} Hz). Find out the maximum wavelength (in Å) in this range.
- For a wave, frequency is 10 Hz and wavelength is 2.5 m. How much distance it will travel in 40 seconds.

❑ PLANCK'S QUANTUM THEORY

◆ According to Planck's quantum theory :

- The radiant energy emitted or absorbed by a body not continuously but discontinuously in the form of small discrete packets of energy and these packets are called quantum.
- In case of light, the smallest packet of energy is called as 'photon' but in general case the smallest packet of energy called as quantum.
- The energy of each quantum is directly proportional to frequency of the radiation i.e.

$$E \propto \nu \Rightarrow E = h\nu \quad \text{or} \quad E = \frac{hc}{\lambda} \quad \left\{ \because \nu = \frac{c}{\lambda} \right\}$$

Proportionality constant or Plank's constant (h)

$$h = 6.626 \times 10^{-37} \text{ kJ sec.}$$

$$\text{or } 6.626 \times 10^{-34} \text{ J sec (1 erg} = 10^{-7} \text{ J)}$$

$$\text{or } 6.626 \times 10^{-27} \text{ erg sec.}$$

4. Total amount of energy transmitted from one body to another will be some integral multiple of energy of a quantum.

$$E = nh\nu$$

Where n is an integer and n = number of quantum

$$E = h\nu = \frac{hc}{\lambda} = hc\bar{\nu}$$

Ex.5 Calculate the energy of a photon of sodium light of wave length $5.862 \times 10^{-16} \text{ m}$ in Joules.

Ans. 3.37×10^{-10}

Sol. $= 5.886 \times 10^{-16} \text{ m}$

$$c = 3 \times 10^8 \text{ m sec}^{-1}$$

$$E = nh\nu \quad \text{or} \quad \frac{nhc}{\lambda} \quad \{\because n = 1\}$$

$$\therefore E = \frac{hc}{\lambda}$$

$$E = \frac{1 \times 6.6 \times 10^{-34} \text{ Jules} \times 3 \times 10^8 \text{ msec}^{-1}}{5.862 \times 10^{-16} \text{ m}} = \frac{6.6 \times 3}{5.862} \times 10^{-10} = 3.37 \times 10^{-10} \text{ J}$$

Ex.6 Calculate the wavelength and frequency of a photon having an energy of 2 eV.

Ans. $6.204 \times 10^{-7} \text{ m}, 4.8 \times 10^{14} \text{ sec}^{-1}$

Sol. $\because 1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$

$$\therefore E = 2 \text{ eV} = 3.204 \times 10^{-19} \text{ J}$$

(a) Calculation of wavelength (λ) :

$$E = \frac{hc}{\lambda} \quad \text{or} \quad \lambda = \frac{hc}{E}$$

$$= \frac{6.626 \times 10^{-34} \text{ Js} \times 3 \times 10^8 \text{ m sec}^{-1}}{3.204 \times 10^{-19} \text{ J}} = 6.204 \times 10^{-7} \text{ m}$$

(b) Calculation of frequency (ν) :

$$\nu = \frac{c}{\lambda} = \frac{3 \times 10^8 \text{ msec}^{-1}}{6.204 \times 10^{-7} \text{ m}}$$

$$= 0.48 \times 10^{15} \text{ sec}^{-1}$$

$$= 4.8 \times 10^{14} \text{ sec}^{-1}$$

Ex.7 Calculate the energy of 100 photons in eV if the wavelength of the light is 2000 \AA .

Ans. 621.1 eV.

Sol. Total energy = No of photons \times Energy of one photon = $100 \times \left(\frac{6.625 \times 10^{-34} \times 3 \times 10^8}{2000 \times 10^{-10}} \right)$

$$= 9.937 \times 10^{-17} \text{ J} = \frac{9.937 \times 10^{-17}}{1.6 \times 10^{-19}} \text{ eV} = 621.1 \text{ eV}$$

Ex.8 The eyes of a certain member of the reptile family pass a visual signal to the brain when the visual receptors are struck by photons of wavelength 850 nm. If a total energy of $3.15 \times 10^{-14} \text{ J}$ is required to trip the signal, what is the minimum number of photons that must strike the receptor. ($h = 6.6 \times 10^{-34}$)

Ans. 1.35×10^5 photons

Sol. $n \times \text{Energy of one photon} = \text{Total energy}$

$$n \times \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{850 \times 10^{-9}} = 3.15 \times 10^{-14} \Rightarrow n = 1.35 \times 10^5 \text{ photons}$$

Ex.9 Iodine molecule dissociates into atoms after absorbing light of 3000 Å. If one quantum of radiation is absorbed by each molecule, calculate the kinetic energy of iodine atoms. (Bond energy of $\text{I}_2 = 240 \text{ kJ (mol)}$).

Ans. $1.318 \times 10^{-19} \text{ J}$

Sol. Energy given to iodine molecule

$$\frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{3000 \times 10^{-10}} = 6.62 \times 10^{-19} \text{ J}$$

Also energy used for breaking up

$$\text{I}_2 \text{ molecule} = \frac{240 \times 10^3}{6.023 \times 10^{23}} = 3.984 \times 10^{-19} \text{ J}$$

$$\therefore \text{Energy used in imparting kinetic to two atoms} = (6.62 - 3.984) \times 10^{-19} \text{ J}$$

$$\therefore \text{KE of iodine atom} = \frac{(6.62 - 3.984)}{2} \times 10^{-19} = 1.318 \times 10^{-19} \text{ J}$$

Ex.10 O_2 undergoes photochemical dissociation into one normal oxygen atom and one oxygen atom 1.967 eV more energetic than normal. The dissociation of O_2 into two normal atom of oxygen requires 498 kJ mol^{-1} . What is the maximum wavelength effective for photo chemical dissociation of O_2 ?

Ans. 1740.2 Å.

Sol. We know





Energy required for simple dissociation of O_2 into two normal atoms = $498 \times 10^3 \text{ J mol}^{-1}$

$$= \frac{498 \times 10^8}{6.023 \times 10^{23}} \text{ J mol}^{-1}$$

If one atom in excited state has more energy, i.e., 1.967 eV

$$= 1.967 \times 1.602 \times 10^{-19} \text{ J}$$

The energy required for photochemical dissociation of O_2

$$\begin{aligned} &= \frac{498 \times 10^3}{6.023 \times 10^{23}} + 1.967 \times 1.602 \times 10^{-19} \\ &= 82.68 \times 10^{-20} + 31.51 \times 10^{-20} = 114.19 \times 10^{-20} \text{ Joule} \end{aligned}$$

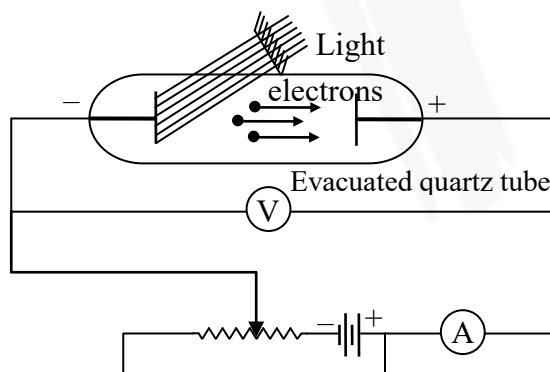
$$E = \frac{hc}{\lambda}$$

$$\begin{aligned} 114.19 \times 10^{-20} &= \frac{6.625 \times 10^{-34} \times 3 \times 10^8}{\lambda} \\ &= 1740.2 \times 10^{-10} \text{ m} = 1740.2 \text{ \AA} \end{aligned}$$

❑ PHOTOELECTRIC EFFECT

Sir J.J. Thomson observed that when a light of certain frequency strikes the surface of a metal, electrons are ejected from the metal. This phenomenon is known as photoelectric effect and the ejected electrons are called photoelectrons.

A few metals, which are having low ionisation energy like Cesium, show this effect under the action of visible light but many more show it under the action of more energetic ultraviolet light.



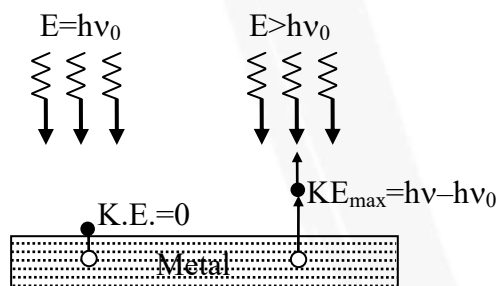
An evacuated tube contains two electrodes connected to a source of variable voltage, with the metal plate whose surface is irradiated as the anode. Some of the photoelectrons that emerge from this surface have enough energy to reach the cathode despite its negative polarity, and

they constitute the measured current. The slower photoelectrons are repelled before they get to the cathode. When the voltage is increased to a certain value V_0 , of the order of several volts, no more photoelectrons arrive, as indicated by the current dropping to zero. This extinction voltage (or also referred as stopping potential) corresponds to the maximum photoelectron kinetic energy i.e. $eV_0 = \frac{1}{2}mv^2$

The experimental findings are summarized as below :

- ◆ Electrons come out as soon as the light (of sufficient energy) strikes the metal surface.
- ◆ The light of any frequency will not be able to cause ejection of electrons from a metal surface. There is a minimum frequency, called the threshold (or critical) frequency, which can just cause the ejection. This frequency varies with the nature of the metal. The higher the frequency of the light, the more energy the photoelectrons have. Blue light results in faster electrons than red light.
- ◆ Photoelectric current is increased with increase intensity of light of same frequency, if emission is permitted, i.e. a bright light yields more photoelectrons than a dim one of the same frequency, but the electron energies remain the same.

Light must have stream of energy particles or quanta of energy ($h\nu$). Suppose, the threshold frequency of light required ejecting electrons from a metal is ν_0 , when a photon of light of this frequency strikes a metal it imparts its entire energy ($h\nu_0$) to the electron.



"This energy enables the electron to break away from the atom by overcoming the attractive influence of the nucleus". Thus each photon can eject one electron. If the frequency of light is less than ν_0 there is no ejection of electron. If the frequency of light is higher than ν_0 (let it be ν), the photon of this light having higher energy ($h\nu$), will impart some energy to the electron that is needed to remove it away from the atom. The excess energy would give a certain velocity (i.e. kinetic energy) to the electron.

$$h\nu = h\nu_0 + K.E.$$

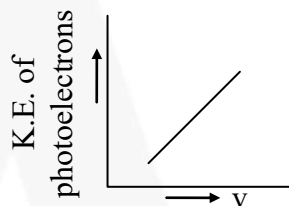
$$h\nu = h\nu_0 + \frac{1}{2}mv^2$$

$$\frac{1}{2}mv^2 = h\nu - h\nu_0$$

where ν = frequency of the incident light

ν_0 = threshold frequency

$h\nu_0$ is the threshold energy (or) the work function denoted by $\phi = h\nu_0$ (minimum energy of the photon to liberate electron). It is constant for particular metal and is also equal to the ionization potential of gaseous atoms. The kinetic energy of the photoelectrons increases linearly with the frequency of incident light. This, if the energy of the ejected electrons is plotted as a function of frequency, it results in a straight line whose slope is equal to Planck's constant 'h' and whose intercept is $h\nu_0$.



Ex.11 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.

Ans. (i) 4.1235 eV, (ii) 3.08×10^{-19} J (iii) 8.22×10^5 ms⁻¹

Sol. (i) Energy of the photon

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

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

$$\text{Therefore } E = \frac{6.6 \times 10^{-19} \text{ J}}{1.6 \times 10^{-19} \text{ J/eV}} = 4.1235 \text{ eV}$$

(ii) Kinetic energy of the emitted photo electron

$$\text{Work function} = 2.20 \text{ eV}$$

$$\text{Therefore, KE} = 4.1235 - 2.20 = 1.9235 \text{ eV} = 3.08 \times 10^{-19} \text{ J}$$

(iii) Velocity of the photo electron

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

$$\text{Therefore, velocity } (v) = \sqrt{\frac{2 \times 3.08 \times 10^{-19}}{9.1 \times 10^{-31}}} = 8.22 \times 10^5 \text{ ms}^{-1}$$

Ex.12 Photoelectrons are liberated by ultra violet light of wavelength 2000 \AA from a metallic surface for which the photoelectric threshold is 4000 \AA . Calculate maximum kinetic energy of electrons emitted with.

Ans. 6.96 eV

Sol. $(KE)_{\max} = \text{Quantum Energy} - \text{Threshold energy}$

$$\begin{aligned}
 &= \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{2000 \times 10^{-10}} - \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{4000 \times 10^{-10}} \\
 &= \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{10^{-10}} \left(\frac{1}{2000} - \frac{1}{4000} \right) \\
 &= 4.969 \times 10^{-19} \text{ Joule.}
 \end{aligned}$$

Ex.13 When certain metal was irradiated with light frequency $0.4 \times 10^{13} \text{ Hz}$ the photo electrons emitted had twice the kinetic energy as did photo electrons emitted when the same metal was irradiated with light frequency $1.0 \times 10^{13} \text{ Hz}$. Calculate threshold frequency (ν_0) for the metal.

Ans. $\nu_0 = 1.6 \times 10^{13} \text{ Hz}$

Sol. $h\nu = h\nu_0 + KE$

$$KE_1 = h(\nu_1 - \nu_0)$$

$$KE_2 = h(\nu_2 - \nu_0) = \frac{KE_1}{2}$$

$$\therefore \frac{\nu_2 - \nu_0}{\nu_1 - \nu_0} = \frac{1}{2} \Rightarrow \frac{1.0 \times 10^{13} - \nu_0}{0.4 \times 10^{13} - \nu_0} = \frac{1}{2} \Rightarrow \nu_0 = 1.6 \times 10^{13} \text{ Hz}$$

DO YOURSELF-2

1. Calculate the frequency & energy of a photon of wave length 4000 \AA .
2. How many photons of lights having a wave length of 5000 \AA are necessary to provide 1 Joule of energy.
3. How many photons are emitted per second by a 5 mW laser operating at 620 nm ?
4. The dissociation energy of H_2 is 150 kJ mol^{-1} . If H_2 is exposed to light energy of wavelength 500 nm , what % of light energy will be converted into kinetic energy ?
5. A photon of 300 nm is absorbed by a gas and then re-emits two photons. One re-emitted photon has wavelength 500 nm . Calculate energy of other photon re-emitted out.
6. Find out the number of photons emitted by a 60 watt bulb in one minute, if wavelength of an emitted photon is 620 nm .

7. The work function for a metal is 4 eV. To emit a photo-electron of zero velocity from the surface of the metal, the wavelength of incident light should be :
 (A) 2700 Å (B) 1700 Å (C) 5900 Å (D) 3100 Å
8. The energy required to remove an electron from metal X is 3.31×10^{-20} J. Calculate the maximum wavelength of light that can photo eject an electron from metal X.
 (A) 40 μm (B) 60 μm (C) 7 μm (D) 5 mm
7. Which of the following statements is/are INCORRECT :
 [More than one options may be correct]
 (A) If light of frequency ν falls on a metal surface having work function $h\nu_0$, photoelectric effect will take place only if $\nu \leq \nu_0$.
 (B) A metal with lesser work function produces more number of photoelectrons if intensity and frequency of radiation is same, as compared to a metal with more work function.
 (C) Photo electric effect is explained by partical nature of photoelectron
 (D) Photo electric effect is explained by wave nature of photoelectron

2.4 BOHR'S ATOMIC MODEL :

[Niels Bohr (1885–1962) Niels Bohr, a Danish physicist received his Ph.D. from the University of Copenhagen in 1911. He then spent a year with J.J. Thomson and Ernest Rutherford in England.]

Assumptions of Bohr's model :

- (I) There are certain orbits around the nucleus such that if electron will be revolving in these orbit, then it does not emit any electromagnetic radiation. These are called stationary orbit for the electron. The necessary centripetal force is produced by attraction forces of nucleus. Coulombic force = Centrifugal force

$$\frac{kq_1q_2}{r^2} = \frac{mv^2}{r}$$

- (II) Angular momentum of the electron in these stationary orbit is always an integral multiple of $\frac{h}{2\pi}$.

$$\text{Angular momentum} = mvr = \frac{nh}{2\pi}$$

That is angular momentum can have values such as $\frac{h}{2\pi}, 2\frac{h}{2\pi}, 3\frac{h}{2\pi}, 4\frac{h}{2\pi}, 5\frac{h}{2\pi}$

but cannot have fractional values such as $1.5\frac{h}{2\pi}, 1.2\frac{h}{2\pi}, .5\frac{h}{2\pi}$

(III) The orbits in which electron can revolve are known as **stationary Orbits** because in these orbits energy of electron is always constant. Each stationary orbit is associated with definite amount of energy therefore these orbits are also called as energy levels and are numbered as 1, 2, 3, 4, 5, or K, L, M, N, O, from the nucleus outwards. Electron can make jump from one stationary orbit to another stationary orbit by absorbing or emitting a photon of energy equal to difference in the energies of the stationary orbit i.e. energy change does not take place in continuous manner.

$$\Delta E = E_{\text{final state}} - E_{\text{initial state}}$$

$$\frac{hc}{\lambda} = \Delta E \quad \Delta E - \text{difference in the energy of orbit}$$

$$\nu = \frac{\Delta E}{h} \quad \text{This is Bohr's frequency rule.}$$

MATHEMATICAL FORMS OF BOHR'S POSTULATES :

2.4.1 Radius of orbits :

Consider, an electron of mass 'm' and charge 'e' revolving around a nucleus of charge +Ze (where, Z = atomic number and e is the charge of the proton) with a tangential velocity 'v' and 'r' is the radius of the orbit in which electron is revolving.

By Coulomb's law, the electrostatic force of attraction between the moving electron and nucleus is Coulombic

Since the electrostatic force balance the centrifugal force, for the stable electron orbit.

$$\frac{mv^2}{r} = \frac{KZe^2}{r^2} \quad (\text{or}) \quad v^2 = \frac{KZe^2}{mr} \quad \dots\dots(1)$$

According to Bohr's postulate of angular momentum quantization, we have

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

$$v = \frac{nh}{2\pi mr}$$

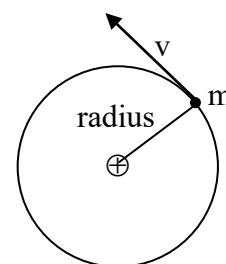
$$v^2 = \frac{n^2 h^2}{4\pi^2 m^2 r^2} \quad \dots\dots(2)$$

From equation (1) and (2)

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

$$\text{On solving we get } r = \frac{n^2 h^2}{4\pi^2 m KZe^2} \quad \dots\dots(3)$$

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



Hence, only certain orbits whose radii are given by the above equation are available for the electron. The greater the value of n , i.e., farther the energy level from the nucleus the greater is the radius. The radius of the smallest orbit ($n = 1$) for hydrogen atom ($Z = 1$) is r_0 .

$$r_0 = \frac{n^2 h^2}{4\pi^2 m e^2 K} = \frac{1^2 \times (6.626 \times 10^{-34})^2}{4 \times (3.14)^2 \times 9 \times 10^{-31} \times (1.6 \times 10^{-19})^2 \times 9 \times 10^9} = 5.29 \times 10^{-11} \text{ m} = 0.529 \text{ \AA}$$

Radius of n^{th} orbit for an atom with atomic number Z is simply written as

$$r_n = 0.529 \times \frac{n^2}{Z} \text{ \AA}$$

Ex.14 Calculate the radius of 1st, 2nd, 3rd, 4th Bohr's Orbit of hydrogen.

Sol. Radius of Bohr's orbit

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

(a) Radius of 1st orbit :

$$r = 0.529 \times \frac{1^2}{1} = 0.529 \text{ \AA}$$

(b) Radius of 2nd orbit :

$$r = 0.529 \times \frac{2^2}{1} = 0.529 \times 4 = 2.116 \text{ \AA}$$

(c) Radius of 3rd orbit :

$$r = 0.529 \times \frac{3^2}{1} = 0.529 \times 9 = 4.761 \text{ \AA}$$

(d) Radius of 4th orbit :

$$r = 0.529 \times \frac{4^2}{1} = 0.529 \times 16 = 8.464 \text{ \AA}$$

Ex.15 The ratio of the radius of two Bohr's orbit of Li^{+2} is 1:9. what Would be their nomenclature.

(A) K & L

(B) L & M

(C) K & M

(D) K & N

Ans. (C)

$$\text{Sol. } \frac{r_x}{r_y} = \frac{1}{9} = \frac{0.529 \times \frac{n_x^2}{3}}{0.529 \times \frac{n_y^2}{3}} \Rightarrow \sqrt{\frac{n_x^2}{n_y^2}} \Rightarrow \sqrt{\frac{1}{9}}$$

$$\frac{n_x}{n_y} = \frac{1}{3} = \frac{\text{K Shell}}{\text{M Shell}}$$

2.4.2 Velocity of electron in orbits :

Angular momentum of the revolving electron in n^{th} orbit is given by

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

$$v = \frac{nh}{2\pi mr}$$

put the value of 'r' in the this equation

$$\text{then, } v = \frac{nh \times 4\pi^2 mZe^2 K}{2\pi mn^2 h^2}$$

$$v = \frac{2\pi Ze^2 K}{nh}$$

on putting the values of π , e , h and K

$$\text{velocity of electron in } n^{\text{th}} \text{ orbit} \quad v_n = 2.18 \times 10^6 \times \frac{Z}{n} \text{ m/sec}$$

$$\text{2.4.2 Time period of revolution of an electron in its orbit} = \frac{2\pi r}{v}$$

$$\text{2.4.3 Frequency of revolution of an electron in its orbit} = \frac{v}{2\pi r}$$

Ex.16 Calculate the velocity of an electron present in the 3^{rd} orbit of the Li^{2+} ion. Also find the number of revolutions per second that it makes around the nucleus.

Sol. Radius of 2^{nd} orbit $= r_1 \times \frac{(n)^2}{Z}$

$$= 0.529 \times 10^{-8} \times \frac{(3)^2}{3} = 1.587 \times 10^{-8} \text{ cm}$$

Velocity of electron in 2^{nd} orbit,

$$v = 2.18 \times 10^8 \frac{Z}{n} \text{ cm/sec} = \frac{2.18 \times 10^8 \times 3}{3} = 2.18 \times 10^8 \text{ cm/sec}$$

$$\text{Number of revolutions/sec} = \frac{1}{2\pi r / v} = \frac{v}{2\pi r} = \frac{2.18 \times 10^8 \text{ cm/sec}}{2 \times 3.14 \times 1.587 \times 10^{-8} \text{ cm}} = 0.2187 \times 10^{16}$$

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

2.4.3 CALCULATION OF ENERGY OF AN ELECTRON :

The total energy (E) of the electron is the sum of kinetic energy and potential energy.

Kinetic energy of the electron $= \frac{1}{2} mv^2$

$$\text{Potential energy} = \int \text{coulombic force} \cdot dr = \int \frac{KZe^2}{r^2} \cdot dr = \frac{-KZe^2}{r}$$

$$\text{Total energy} = \frac{1}{2} mv^2 - \frac{-KZe^2}{r} \quad \dots(4)$$

From equation (1) we know that

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

$$\therefore \frac{1}{2} mv^2 = \frac{KZe^2}{r^2}$$

Substituting this in equation (4)

$$\text{Total energy (E)} = \frac{KZe^2}{2r} - \frac{KZe^2}{r} = -\frac{KZe^2}{2r}$$

Substituting for r, gives us

$$E = \frac{2\pi^2 mZ^2 e^4 K^2}{n^2 h^2} \quad \text{where } n = 1, 2, 3, \dots$$

This expression shows that only certain energies are allowed to the electron. Since this energy expression consist of so many fundamental constant, we are giving you the following simplified expressions. Putting the value of m,e,h and π we get the expression of total energy

$$\begin{aligned} \text{T.E.} = E_n &= 21.8 \times 10^{-19} \times \frac{Z^2}{n^2} \text{ J per atom} \\ &= -13.6 \times \frac{Z^2}{n^2} \text{ eV per atom} \quad (1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}) \\ &= -21.8 \times 10^{-12} \times \frac{Z^2}{n^2} \text{ erg per atom} \quad (\text{eV} = 1.602 \times 10^{-12} \text{ erg}) \\ &= -313.6 \times \frac{Z^2}{n^2} \text{ Kcal/mole} \quad (1 \text{ cal} = 4.18 \text{ J}) \end{aligned}$$

The energies are negative since the energy of the electron in the atom is less than the energy of a free electron, i.e. the electron is at infinite distance from the nucleus which is taken as zero. The lowest energy level of the atom corresponds to $n = 1$.

When $n = \infty$, $E = 0$, which corresponds to an ionized atom, i.e. the electron and nucleus are infinitely separated.

Total Energy = Potential Energy

$$\text{Total Energy} = -\frac{1}{2} \text{ Kinetic Energy.}$$

Ex.17 Calculate the energy of for 3rd state Li⁺² ion.

Ans. - 13.6 eV/atom

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

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

$$\begin{aligned}\therefore E &= -13.6 \times \frac{(3)^2}{(3)^2} \\ &= -13.6 \text{ eV/atom}\end{aligned}$$

Ex.18 If the potential energy of an electron is in hydrogen atom -6.8 eV, then find kinetic energy and total energy of electron in this orbit. Also find radius of this orbit.

Ans. (K.E. = 3.4 eV, T.E. = - 3.4 eV, $r = 2.16 \text{ \AA}$)

Sol. 1. P.E. = -2K.E. $\Rightarrow -6.8 = -2\text{K.E.}$

K.E. = 3.4 eV

2. T.E. = - K.E. = - 3.4 eV

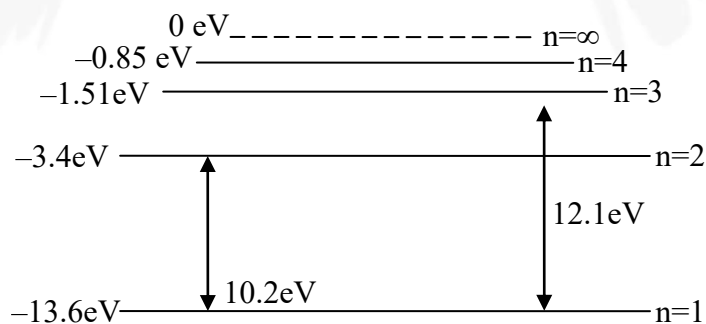
3. $\therefore E = -13.6 \times \frac{Z^2}{n^2}$ $\therefore -3.4 = -13.6 \times \frac{1^2}{n^2}$

$\Rightarrow n^2 = \frac{-13.6}{-3.4} = 4$ i.e. $n = 2$

4. $r = 0.529 \times \frac{n^2}{Z} \text{ \AA}$ $\Rightarrow r = 0.529 \times \frac{(2)^2}{1} \text{ \AA}$
 $= 0.529 \times 4 \text{ \AA} = 2.16 \text{ \AA}$

2.4.4 Energy Level Diagram :

- Orbit of lowest energy is placed at the bottom, and all other orbits are placed above this.
- The gap between two orbits is proportional to the energy difference of the orbits.



Energy level diagram of H-atom

2.4.5 Definition valid for single electron System :

- (I) Ground state : Lowest energy state of any atom or ion is called ground state of the atom.
For Ground state $n = 1$.

Ground state energy of H-atom = -13.6 eV

Ground state energy of He^+ Ion = -54.4 eV

- (II) Excited State : States of atom other than the ground state are called excited states :

$n = 2$ first excited state

$n = 3$ second excited state

$n = 4$ third excited state

$n = n + 1$ n^{th} excited state

- (III) Ionisation energy (IE) : Minimum energy required to move an electron from ground state to $n = \infty$ is called ionisation energy of the atom or ion.

Ionisation energy = $13.6 \times Z^2 \text{ eV}$

Ionisation energy of H-atom = 13.6 eV

Ionisation energy of He^+ ion = 54.4 eV

Ionisation energy of Li^{+2} ion = 122.4 eV

- (IV) Ionisation Potential (I.P.) : Potential difference through which a free electron must be accelerated from rest, such that its kinetic energy becomes equal to ionisation energy of the atom or ion is called ionisation potential.

I.P. of H atom = 13.6 V , I.P. of He^+ Ion = 54.4 V

- (V) Excitation Energy : Energy required to move an electron from ground state of the atom to any other state of the atom or ion is called excitation energy of that state. 1st excitation energy = 10.2 eV .

$$\text{Excitation Energy} = E_{n_2} - E_{n_1} = \frac{-13.6Z^2}{n_2^2} - \left(\frac{-13.6Z^2}{n_1^2} \right) = 13.6Z^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right) \text{ eV}$$

Where $n_1 = 1$

- (VI) Excitation Potential : Potential difference through which an electron must be accelerated from rest to so that its kinetic energy become equal to excitation energy of any state is called excitation potential of that state.

- (VII) Binding Energy 'or' Separation Energy : Energy required to move an electron from any state to $n = \infty$ is called binding energy of that state.

Binding energy of ground state = I.E. of atom or Ion.

Ex.19 A single electron system has ionization energy $11180 \text{ kJ mol}^{-1}$. Find the number of protons in the nucleus of the system.

Ans. $Z = 3$

Sol.
$$\text{I.E.} = \frac{Z^2}{n^2} \times 21.69 \times 10^{-19} \text{ J}$$

$$= \frac{11180 \times 10^3}{6.023 \times 10^{23}} = \frac{Z^2}{1^2} \times 21.69 \times 10^{-19} \Rightarrow Z = 3$$

Ex.20 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.

Ans. 10.2 eV

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, $E_2 - E_1 = -3.4 + 13.6 = 10.2 \text{ eV}$

DO YOURSELF-3

- Calculate radius ratio for 2nd orbit of He^+ ion & 3rd orbit of Be^{3+} ion.
- If radius of third stationary orbit (in Bohr's atom) is R. Then radius of fourth orbit will be
 (A) $R/5$ (B) $9R$ (C) $9R/16$ (D) $16R/9$
- If the radius of the first Bohr orbit of the H atom is r, then for Li^{2+} ion, it will be :
 (A) $3r$ (B) $9r$ (C) $r/3$ (D) $r/9$
- The energy of an excited H-atom is -1.51 eV. Angular momentum of e^- in the given orbit will be:
 (A) $3h/\pi$ (B) $3h/2\pi$ (C) $2h/\pi$ (D) h/π
- The radius of the an orbit of Be^{+3} ion is 0.529 \AA . The velocity of electron in this orbit will be
 (A) $0.545 \times 10^6 \text{ m/s}$ (B) $2.18 \times 10^6 \text{ m/s}$
 (C) $4.36 \times 10^6 \text{ m/s}$ (D) $1.09 \times 10^6 \text{ m/s}$

6. Match the following :

Column (I)

- (A) Binding energy of 5th excited state of Li^{2+} sample
 (B) 1st excitation potential of H-atom
 (C) 2nd excitation potential of He^+ ion
 (D) I.E. of H-atom

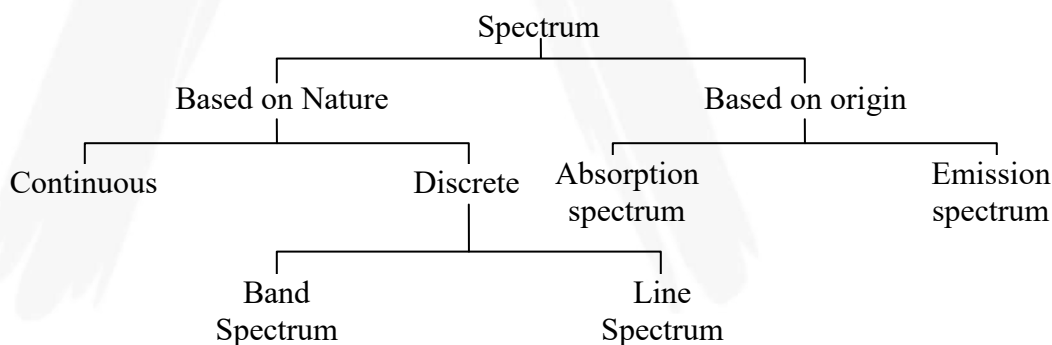
Column (II)

- (p) 10.2 V
 (q) 3.4 eV
 (r) 13.6 eV
 (s) 48.4 V

7. Choose the correct statement:
- (A) The order of velocity is $v_1 < v_2 < v_3 < v_4$ (v_n : where n is orbit number for a given atom)
 (B) The order of total energy is $E_1 > E_2 > E_3 > E_4$ (E_n : where n is orbit number for a given atom)
 (C) The order of velocity of electron in second Bohr orbit is $\text{Be}^{3+} < \text{Li}^{+2} < \text{He}^+ < \text{H}$
 (D) The order of Bohr radius is $r_1 < r_2 < r_3 < r_4$ (r_n : where n is orbit number for a given atom)
8. When an electron drops from a higher energy level to a low energy level, then :
- (A) energy is absorbed (B) energy is emitted
 (C) atomic number increases (D) atomic number decreases
9. In hydrogen atom, energy of first excited state is -3.4 eV . Then, KE of same orbit of hydrogen atom is :
- (A) $+3.4 \text{ eV}$ (B) $+6.8 \text{ eV}$ (C) -13.6 eV (D) $+13.6 \text{ eV}$

❑ ELECTROMAGNETIC SPECTRUM :

When a radiation is passed through a spectroscope (Prism) for the dispersion of the radiation, the pattern (photograph) obtained on the screen (photographic plate) is called as spectrum of the given radiation. The arrangement obtained by arranging various types of electromagnetic waves in orders of their increasing frequency or decreasing wave length is called as electromagnetic spectrum. The branch or science dealing with the study of spectra is called **spectroscopy**.



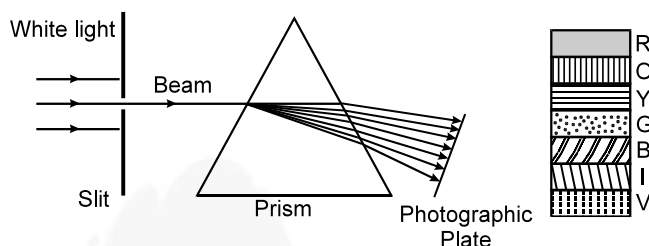
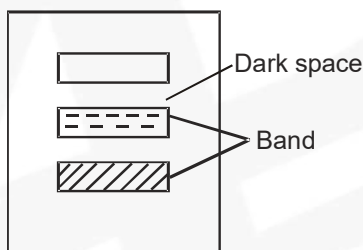
(I) Emission spectra :

When the radiation emitted from some source e.g. from the sun or by passing electric discharge through a gas at low pressure or by heating some substance to high temperature etc, is passed directly through the prism and then received on the photographic plate, the spectrum obtained is called 'Emission spectrum'.

Depending upon the source of radiation, the emission spectra are mainly of two type :

(a) Continuous spectra :

When white light from any source such as sun, a bulb or any hot glowing body is analysed by passing through a prism it is observed that it splits up into seven different wide band of colours from violet to red. These colours are so continuous that each of them merges into the next. Hence the spectrum is called continuous spectrum.

**(b) Discrete spectra : It is of two type****(i) Band spectrum**

Band spectrum contains colourful continuous bands separated by some dark space. Generally, molecular spectrum are band spectrum.

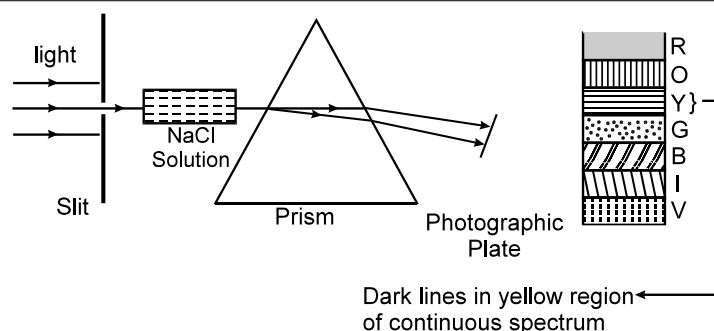
(ii) Line Spectrum :

This is the ordered arrangement of lines of particular wavelength separated by dark space eg. hydrogen spectrum.

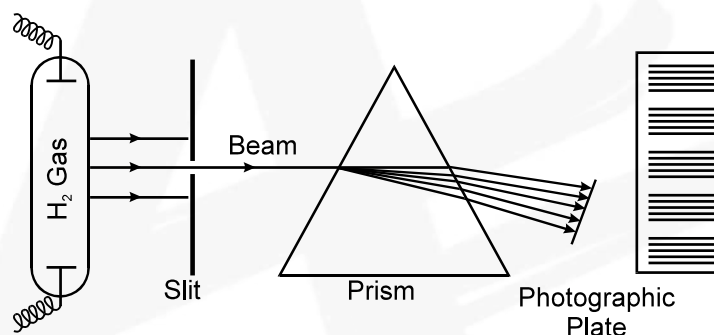
Line spectrum can be obtained from atoms.

(II) Absorption spectra :

When white light from any source is first passed through the solution or vapours of a chemical substance and then analysed by the spectroscopy, it is observed that some dark lines are obtained in the continuous spectrum. These dark lines are supposed to result from the fact that when white light (containing radiations of many wavelengths) is passed through the chemical substance, radiations of certain wavelengths are absorbed, depending upon the nature of the element.



2.5 EMISSION SPECTRUM OF HYDROGEN : 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 line 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.

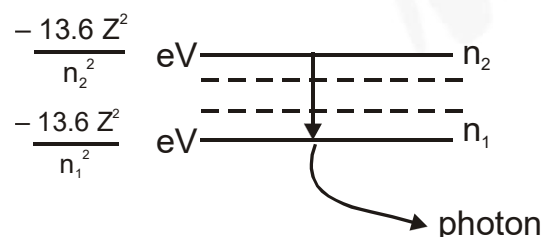


When hydrogen gas at low pressure is taken in the discharge tube and the light emitted on passing electric discharge is examined with a spectroscope, the spectrum obtained is called the emission spectrum of hydrogen.

Line Spectrum of Hydrogen :

Line spectrum of hydrogen is observed due to excitation or de-excitation of electron from one stationary orbit to another stationary orbit

Let electron make transition from n_2 to n_1 ($n_2 > n_1$) in a H-like sample



* Energy of emitted photon $= (\Delta E)_{n_2 \rightarrow n_1} = \frac{-13.6Z^2}{n_2^2} - \left(\frac{-13.6Z^2}{n_1^2} \right) = 13.6Z^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$

- * Wavelength of emitted photon

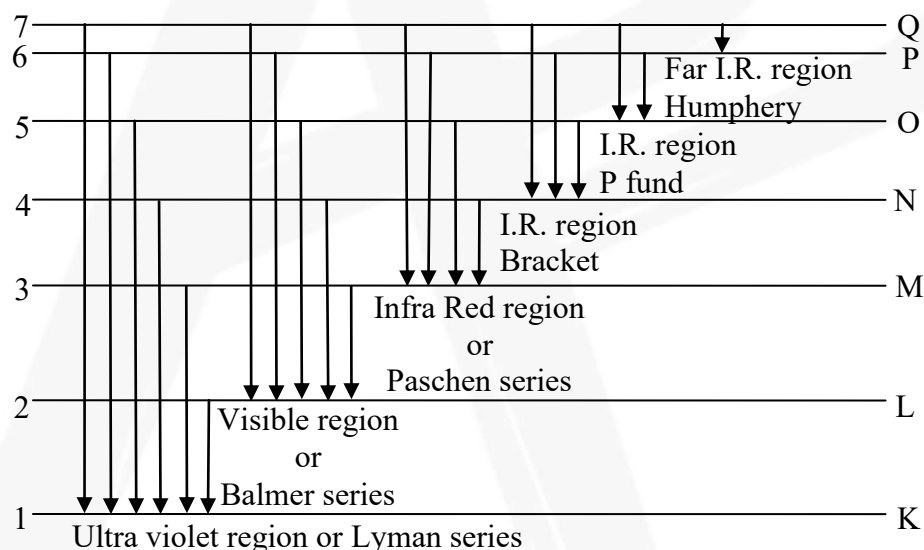
$$\lambda = \frac{hc}{(\Delta E)_{n_2 \rightarrow n_1}}$$

$$\lambda = \frac{hc}{13.6Z^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)}$$

$$\frac{1}{\lambda} = \frac{(13.6)Z^2}{hc} \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

- * Wave number, $\frac{1}{\lambda} = \bar{\nu} = RZ^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$

R = Rydberg constant = $1.09678 \times 10^7 \text{ m}^{-1}$; $R_{\text{H}} = 1.1 \times 10^7 \text{ m}^{-1}$; $R = \frac{13.6 \text{ eV}}{hc}$; $R_{\text{H}} = 13.6 \text{ eV}$



2.5.1 SPECTRA LINES OF HYDROGEN ATOM :

(I) LYMAN SERIES

- * It is first spectral series of H.
- * It was found to be in ultraviolet region by Lyman in 1898.
- * For it value of $n_1 = 1$ and $n_2 = 2, 3, 4$ where ' n_1 ' is ground state and ' n_2 ' is called excited state of electron present in a H - atom.

* $\frac{1}{\lambda} = R_{\text{H}} \left[\frac{1}{1^2} - \frac{1}{n_2^2} \right]$ where $n_2 > 1$ always.

- * The wavelength of marginal line (i.e. $n_2 = \infty$) = $\frac{n_1^2}{R_{\text{H}}}$ for all series. So for lyman series $\lambda = \frac{1}{R_{\text{H}}}$.

- * 1st line of lyman series $\Rightarrow 2 \rightarrow 1$
- * 2nd line of lyman series $= 3 \rightarrow 1$
- * Last line of lyman series $= \infty \rightarrow 1$
- * $[10.2 \text{ eV} \leq (\Delta E)_{\text{lyman}} \leq 13.6 \text{ eV}]$

$$\frac{12400}{13.6} \leq \lambda_{\text{lyman}} \leq \frac{12400}{10.2} \text{ A}^\circ$$

- * **Longest line** : longest wavelength line λ_{longest} or $\lambda_{\text{max.}} = \frac{12400}{(\Delta E)_{\text{min}}}$
- * **Shortest line** : shortest wavelength line $\lambda_{\text{shortest}}$ or $\lambda_{\text{min}} = \frac{12400}{(\Delta E)_{\text{max}}}$
- * First line of any spectral series is the longest (λ_{max}) line.
- * Last line of any spectral series is the shortest (λ_{min}) line.

Series limit :

It is the last line of any spectral series.

$$\text{Wave no of 1st line of Lyman series} = \frac{1}{\lambda} = \bar{\nu} = R \times 1^2 \left(\frac{1}{1^2} - \frac{1}{2^2} \right)$$

$$\bar{\nu} = R \times 1^2 \left(\frac{4-1}{4} \right) \Rightarrow \bar{\nu} = \frac{R \times 3}{4} = \frac{R \times 3}{4}$$

$$\therefore \left[\lambda = \frac{4}{3R} \right]$$

Wave no of last line of Lyman series

$$\bar{\nu} = R \times 1^2 \left(\frac{1}{1^2} - \frac{1}{\infty^2} \right) \Rightarrow \bar{\nu} = R$$

For Lyman series,

$$\lambda_{\text{longest}} = \frac{12400}{(\Delta E)_{2 \rightarrow 1}}, \lambda_{\text{shortest}} = \frac{12400}{(\Delta E)_{\infty \rightarrow 1}}$$

(II) BALMER SERIES :

- * It is the second series of H-spectrum.
- * It was found to be in visible region by Balmer in 1892.
- * For it value of $n_1 = 2$ and $n_2 = 3, 4, 5, \dots$
- * The wavelength of marginal line of Balmer series $= \frac{n_1^2}{R_H} = \frac{2^2}{R_H} = \frac{4}{R_H}$

$$* \quad \frac{1}{\lambda} = R_H \left(\frac{1}{2^2} - \frac{1}{n_2^2} \right) \text{ where } n_2 > 2 \text{ always.}$$

$$1.9 \leq (\Delta E)_{\text{balmer}} \leq 3.4 \text{ eV.}$$

All the lines of balmer series in H spectrum are not in the visible range. Infact only 1st 4 lines belongs to visible range.

$$\frac{12400}{3.4} \text{ Å} \leq \lambda_{\text{balmer}} \leq \frac{12400}{1.9} \text{ Å} \quad \Rightarrow \quad 3648 \text{ Å} \leq \lambda_{\text{balmer}} \leq 6536 \text{ Å}$$

Lines of balmer series (for H atom) lies in the visible range.

1st line of balmer series = $3 \rightarrow 2$

last line of balmer series = $\infty \rightarrow 2$

$$(\bar{\nu}) \text{ 1}^{\text{st}} \text{ line} = R \times 1 \left(\frac{1}{2^2} - \frac{1}{3^2} \right) = \frac{5R}{36}$$

$$(\bar{\nu}) \text{ last line} = R \left(\frac{1}{2^2} - \frac{1}{\infty^2} \right) = \frac{R}{4}$$

(III) PASCHEN SERIES :

(a) It is the third series of H - spectrum.

(b) It was found to be in infrared region by Paschen.

(c) For it value of $n_1 = 3$ and $n_2 = 4, 5, 6 \dots\dots\dots$

(d) The wavelength of marginal line of Paschen series = $\frac{n_1^2}{R_H} = \frac{3^2}{R_H} = \frac{9}{R_H}$.

(e) $\frac{1}{\lambda} = R_H \left[\frac{1}{3^2} - \frac{1}{n_2^2} \right]$ where $n_2 > 3$ always.

(IV) BRACKETT SERIES :

(a) It is fourth series of H - spectrum.

(b) It was found to be in infrared region by Brackett.

(c) For it value of $n_1 = 4$ and $n_2 = 5, 6, 7 \dots\dots\dots$

(d) The wavelength of marginal line of brackett series = $\frac{n_1^2}{R_H} = \frac{4^2}{R_H} = \frac{16}{R_H}$

(e) $\frac{1}{\lambda} = R_H \left[\frac{1}{4^2} - \frac{1}{n_2^2} \right]$ where $n_2 > 4$ always.

(V) PFUND SERIES :

- (a) It is fifth series of H- spectrum.
- (b) It was found to be in infrared region by Pfund.
- (c) For it value of $n_1 = 5$ and $n_2 = 6, 7, 8, \dots$ where n_1 is ground state and n_2 is excited state.
- (d) The wavelength of marginal line of Pfund series = $\frac{n_1^2}{R_H} = \frac{5^2}{R_H} = \frac{25}{R_H}$
- (e) $\frac{1}{\lambda} = R_H \left[\frac{1}{5^2} - \frac{1}{n_2^2} \right]$ where $n_2 > 5$ always.

(VI) HUMPHRY SERIES :

- (a) It is the sixth series of H-spectrum.
- (b) It was found to be in infrared region by Humphry.
- (c) For it value of $n_1 = 6$ and $n_2 = 7, 8, 9, \dots$
- (d) The wavelength of marginal line of Humphry series = $\frac{n_1^2}{R_H} = \frac{6^2}{R_H} = \frac{36}{R_H}$
- (e) $\frac{1}{\lambda} = R_H \left[\frac{1}{6^2} - \frac{1}{n_2^2} \right]$ where $n_2 > 6$.

2.5.2 Number of photons emitted by a sample of H atom :

If an electron is in any higher state $n = n$ and makes a transition to ground state, then total **number** of different photons emitted is equal to $\frac{n \times (n-1)}{2}$.

- * If an electron is in any higher state $n = n_2$ and makes a transition to another excited state $n = n_1$, then total **number** of different photons emitted is equal to $\frac{\Delta n (\Delta n + 1)}{2}$, where $\Delta n = n_2 - n_1$
- * **Note :** In case of single isolated atom if electron make transition from n^{th} state to the ground state then max. number of spectral lines observed = $(n-1)$

Ex.21 Calculate the wavelength of a photon emitted when an electron in H- atom make a transition from $n = 2$ to $n = 1$.

Ans. $\lambda = \frac{4}{3R}$

Sol. $\frac{1}{\lambda} = RZ^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$

$$\therefore \frac{1}{\lambda} = R(1)^2 \left[\frac{1}{1^2} - \frac{1}{2^2} \right]$$

$$\therefore \frac{1}{\lambda} = \frac{3R}{4} \text{ or } \lambda = \frac{4}{3R}$$

Ex.22 Calculate wavelength for 2nd line of Balmer series of He⁺ ion.

Ans. $\lambda = \frac{4}{3R}$

Sol. $\frac{1}{\lambda} = R(2)^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$

$$n_1 = 2 \quad n_2 = 4$$

$$\frac{1}{\lambda} = R(2^2) \left[\frac{1}{2^2} - \frac{1}{4^2} \right]$$

$$\frac{1}{\lambda} = \frac{3R}{4} \quad \lambda = \frac{4}{3R}$$

Ex.23 Calculate the frequency of the last line of the Lyman series in hydrogen spectrum.

Ans. $3.29 \times 10^{15} \text{ sec}^{-1}$

Sol. For last line of Lyman series $n_1 = 1, n_2 = \infty$

$$\frac{1}{\lambda} = RZ^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right) = R \left(\frac{1}{1} - 0 \right)$$

$$\frac{1}{\lambda} = R$$

$$\frac{1}{\lambda} = 109700 \text{ cm}^{-1}$$

$$\begin{aligned} \nu &= \frac{c}{\lambda} = c \times \frac{1}{\lambda} = c \times R \\ &= 3 \times 10^8 \text{ m sec}^{-1} \times 109700 \text{ cm}^{-1} \\ &= 3 \times 10^{10} \text{ cm sec}^{-1} \times 109700 \text{ cm}^{-1} \\ &= 3.29 \times 10^{15} \text{ sec}^{-1} \end{aligned}$$

Ex.24 What will be the shortest and longest wavelength of absorption lines of hydrogen gas containing atoms in ground state ? (Given $R = 109737.5 \text{ cm}^{-1}$)

Ans. 911 Å, 1215 Å

Sol. $\frac{1}{\lambda} = RZ^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$

For shortest wavelength ΔE should be maximum for that $n_1 = 1, n_2 = \infty$

$$\frac{1}{\lambda} = 109737.5 \text{ cm}^{-1} \quad 1 \left[\frac{1}{1^2} - \frac{1}{\infty} \right] = 109737.5 \text{ cm}^{-1} = 911 \times 10^{-8} \text{ cm} = 911 \text{ Å}$$

For largest wavelength ΔE should be minimum so $n_1 = 1$, $n_2 = 2$

$$\frac{1}{\lambda} = 109737.5 \text{ cm}^{-1} \times \left[\frac{1}{1^2} - \frac{1}{2^2} \right] = 1215 \text{ \AA}$$

Ex.25 In a hydrogen spectrum if electron moves from 6th to 3rd orbit by transition in multi steps then find out the following steps :

- (a) Total number of lines in spectrum (b) Total number of lines in U.V. region
(c) Total number of lines in visible region (d) Total number of lines in IR region

Ans. (a) 6 (b) Zero (c) Zero (d) 6

Sol. (a) Calculation of total number of lines :

$$= \frac{(n_2 - n_1)(n_2 - n_1 + 1)}{2} = \frac{(6 - 3)(6 - 3 + 1)}{2} = \frac{3 \times 4}{2} = 6$$

(b) Calculation of number lines present in U.V. region.

e^- moves from 6th to 3rd orbit in multisteps.

For U.V. region, e^- should be comes into 1st shell. So the number of lines in U.V. region zero.

(c) Calculation of total number of lines in visible region.

For visible region, e^- should be comes into 2nd shell, so the number of lines in visible region zero.

(d) Calculation of total number of lines in I.R. region.

In I.R. region, Paschen, Bracket and P fund series are present.

$$\begin{aligned} \text{Number of lines in Paschen series} &= n_2 - 3 \\ &= 6 - 3 \\ &= 3 \end{aligned}$$

$$\begin{aligned} \text{Number of lines in Bracket series} &= n_2 - 4 \\ &= 6 - 4 \\ &= 2 \end{aligned}$$

$$\begin{aligned} \text{Number of lines in P fund series} &= n_2 - 5 \\ &= 6 - 5 \\ &= 1 \end{aligned}$$

$$\text{So total number of lines} = 3 + 2 + 1 = 6$$

DO YOURSELF-4

- To which electronic transition between Bohr orbits in hydrogen, the second line in the Balmer series belongs?
(A) $3 \longrightarrow 2$ (B) $4 \longrightarrow 2$ (C) $5 \longrightarrow 2$ (D) $6 \longrightarrow 2$
- Wave number of a spectral line for a given transition is $x \text{ cm}^{-1}$ for He^+ ion. Then, its value for Be^{3+} ion for same transition is :
(A) $x \text{ cm}^{-1}$ (B) $4x \text{ cm}^{-1}$ (C) $\frac{x}{4} \text{ cm}^{-1}$ (D) $2x \text{ cm}^{-1}$
- The ratio of the wave lengths of last lines of Balmer and Lyman series is -
(A) 4 : 1 (B) 27 : 5 (C) 3 : 1 (D) 9 : 4
- The difference between the wave number of 1st line of Balmer series and last line of Paschen series for Li^{2+} ion is :
(A) $\frac{R}{36}$ (B) $\frac{5R}{36}$ (C) $4R$ (D) $\frac{R}{4}$

Ex.26 A series of lines in the spectrum of atomic hydrogen lies at wavelengths 656.46, 482.7, 434.17, 410.29 nm. What is the wavelength of next line in this series.

Ans. 397.2 nm

Sol. The give series of lines are in the visible region and thus appears to be Balmer series

Therefore, $n_1 = 2$ and $n_2 = ?$ for next line

If $\lambda = 410.29 \times 10^{-7} \text{ cm}$ and $n_1 = 2$

n_2 may be calculated for the last line

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

$$\frac{1}{410.29 \times 10^{-7}} = 109737 \left[\frac{1}{2^2} - \frac{1}{n_2^2} \right]$$

$$n_2 = 6$$

Thus next line will be obtained during the jump of electron from 7th to 2nd shell, i.e.

$$\frac{1}{\lambda} = R \left[\frac{1}{2^2} - \frac{1}{7^2} \right] = 109737 \left[\frac{1}{4} - \frac{1}{49} \right]$$

$$= 397.2 \times 10^{-7} \text{ cm} = 397.2 \text{ nm}$$

Ex.27 If electron make transition from 7th excited state to 2nd state in H atom sample find the max. number of spectral lines observed.

Ans. 21

Sol. $\Delta n = 8 - 2 = 6$

$$\text{spectral lines} = 6 \left(\frac{6+1}{2} \right) = 6 \times \frac{7}{2} = 21$$

Ex.28 In a 1 electron species, the wavelength of an emitted photon is $\frac{9}{8R}$. Which of the following is the possible species, if this line is 2nd line of Lyman series ? R = Rydberg's constant)

(A) He⁺

(B) H⁺

(C) H

(D) He

Sol. $\lambda = \frac{9}{8R} \Rightarrow \bar{\nu} = \frac{8R}{9}$

$$\frac{8R}{9} = RZ^2 \left(\frac{1}{1^2} - \frac{1}{3^2} \right) = RZ^2 \times \frac{8}{9}$$

$$\Rightarrow Z^2 = 1 \Rightarrow Z = 1$$

Ex.29 The wave number of the first line of Balmer series of hydrogen is 15200 cm⁻¹. The wave number of the corresponding line of Li²⁺ ion is-

(A) 15200 cm⁻¹

(B) 60800 cm⁻¹

(C) 76000 cm⁻¹

(D) 136800 cm⁻¹

Sol. According to Rydberg formula $\bar{\nu} \propto Z^2$

$$\text{so apply } \frac{\bar{\nu}_1}{\bar{\nu}_2} = \frac{Z_1^2}{Z_2^2}$$

Ex.30 Statement-1: We can use two photons successively of 1240 Å and 2000 Å wavelength in order to ionise a H atom from ground state.

Statement-2: Sum of the energies of both the photons is greater than IE of H atom.

(A) Statement-1 is True, Statement-2 is True; Statement-2 is a correct explanation for Statement-1.

(B) Statement-1 is True, Statement-2 is True; Statement-2 is NOT a correct explanation for Statement-1

(C) Statement-1 is True, Statement-2 is False

(D) Statement-1 is False, Statement-2 is True

Sol. Both the photons will not be absorbed by the electron of H-atom as the energy levels are quantized.

$$\text{Sum of energies of both photons} = \frac{12400}{1240} + \frac{12400}{2000} = 10 + 6.2 = 16.2 \text{ eV} > (\text{IE})_{\text{H}}$$

2.5.6 Limitation of the Bohr's model :

1. Bohr's theory does not explain the spectrum of multi electron atom.
2. Why the Angular momentum of the revolving electron is equal to $\frac{nh}{2\pi}$, has not been explained by Bohr's theory.
3. Bohr interrelate quantum theory of radiation and classical law of physics with out any theoretical explanation. This was the biggest drawback of this model.
4. Bohr's theory does not explain the fine structure of the spectral lines. Fine structure of the spectral line is obtained when spectrum is viewed by spectroscope of more resolution power.
5. Bohr theory does not explain the spilting of spectral lines in the presence of magnetic field (Zemman's effect) or electric field (Stark's effect)

2.6 de-BROGLIE HYPOTHESIS (Dual nature of electron):

- (a) Einstein had suggested that light can behave as a wave as well as like a particle i.e. it has dual character.
- (b) In 1924, de-Broglie proposed that an electron behaves both as a material particle and as a wave.
- (c) This proposed a new theory, the wave mechanical theory of matter. According to this theory, the electrons protons and even atom when in motion possess wave properties.
- (d) According to de-Broglie, the wavelength associated with a particle of mass m , moving with velocity v is given by the relation,

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

where h is Planck's constant

- (e) This can be derived as follows according to Planck's equation.

$$E = h \nu = \frac{h.c}{\lambda}$$

Energy of photon on the basis of Einstein's mass energy relationship

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

Equating both we get

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

Which is same as de - Broglie relation.

This was experimentally verified by Davisson and Germer by observing diffraction effects with an electron beam.

$$* \quad \text{K.E.} = \frac{1}{2} mv^2$$

$$m (\text{K.E.}) = \frac{1}{2} m^2 v^2 \text{ multiplied by mass on both side}$$

$$\Rightarrow m.v. = \sqrt{2m(\text{K.E.})}$$

$$\lambda = \frac{h}{\sqrt{2m(\text{K.E.})}}$$

* If a charge q is accelerated through a potential difference of 'V' volt from rest then K.E. of the charge is equal to " $q.V$ "

$$\Rightarrow \lambda = \frac{h}{\sqrt{2m(q.V)}}$$

* If an electron is accelerated through a potential difference of 'V' volt from rest then :

$$\Rightarrow \lambda = \frac{h}{\sqrt{2m_e(eV)}}$$

$$\Rightarrow \lambda = \left(\frac{150}{V} \right)^{\frac{1}{2}} \text{ \AA} \quad (\text{on putting values of } h, m_e \text{ and } e)$$

$$\lambda = \frac{12.3}{\sqrt{V}} \text{ \AA} \quad (V \text{ in volt})$$

* If we associate Bohr's theory with de - Broglie equation then

$$2\pi r = n\lambda \quad \text{or} \quad \lambda = \frac{2\pi r}{n}$$

From de-Broglie equation

$$\lambda = \frac{h}{mv} \quad \text{therefore} \quad \frac{h}{mv} = \frac{2\pi r}{n}$$

$$\text{so,} \quad mvr = n \times \frac{h}{2\pi}$$

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

$$mv = \frac{h}{\lambda} \quad \text{putting this in} \quad mvr = \frac{nh}{2\pi}$$

$$\therefore \frac{h}{\lambda} r = \frac{nh}{2\pi} \Rightarrow \left[\lambda = \frac{2\pi r}{n} \right] \quad \text{de Broglie wavelength}$$

Ex.31 Calculate the de Broglie wavelength of a ball of mass 0.1 kg moving with a speed of 30 ms^{-1} .

Ans. $2.2 \times 10^{-34} \text{ m}$

Sol.
$$= \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{0.1 \times 30}$$
$$= 2.2 \times 10^{-34} \text{ m}$$

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.

Since, we come across macroscopic objects in our everyday life, de Broglie relationship has no significance in everyday life.

Ex.32 Two particles X and Y are in motion. If the wavelength associated with particle X is $4 \times 10^{-8} \text{ m}$, calculate the wavelength associated with particle Y if its momentum is half of X.

Ans. $8 \times 10^{-8} \text{ m}$

Sol. According to de Broglie equation

$$\lambda_x = \frac{h}{p_x} \text{ and } \lambda_y = \frac{h}{p_y}$$

$$\frac{\lambda_x}{\lambda_y} = \frac{p_y}{p_x}$$

But $p_y = \frac{1}{2} p_x$ (given)

$$\frac{\lambda_x}{\lambda_y} = \frac{1/2 p_x}{p_x} = \frac{1}{2}$$

$$\lambda_y = 2\lambda_x = 2 \times 4 \times 10^{-8} \text{ m} = 8 \times 10^{-8} \text{ m}$$

2.7 Heisenberg's 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 exact position and momentum of a fast moving particle cannot be calculated precisely at the same moment of time. If Δx is the error in the measurement of position of the particle and if Δp is the error in the measurement of momentum of the particle, then:

$$\Delta x \cdot \Delta p \geq \frac{h}{4\pi} \quad \text{or} \quad \Delta x \cdot (m\Delta v) \geq \frac{h}{4\pi}$$

where, Δx = uncertainty in position, Δp = uncertainty in momentum
 h = Plank's constant, m = mass of the particle
 Δv = uncertainty in velocity

* If the position of a particle is measured precisely, i.e. $\Delta x \rightarrow 0$ then $\Delta p \rightarrow \infty$.

If the momentum of the particle is measured precisely. i.e. $\Delta p \rightarrow 0$ then $\Delta x \rightarrow \infty$.

This is because of a principle of optics that if a light of wavelength ' λ ' is used to locate the position of a particle then maximum error in the position measurement will be $\pm \lambda$. i.e. $\Delta x = \pm \lambda$

If $\Delta x \rightarrow 0$; $\lambda \rightarrow 0$

But, $p = \frac{h}{\lambda} \Rightarrow p \rightarrow \infty$.

So, to make $\Delta x \rightarrow 0$, $\lambda \rightarrow 0$ a photon of very high energy is used to locate it.

\therefore When this photon will collide with the electron then momentum of electron will get changed by a large amount.

* $\Delta p \cdot \Delta x \geq \frac{h}{4\pi}$ (multiplied & divided by Δt)

$$\frac{\Delta P}{\Delta t} \Delta t \cdot \Delta x \geq \frac{h}{4\pi} \quad \left(\frac{\Delta P}{\Delta t} = \text{rate of change in momentum} = F \right)$$

$$F \cdot \Delta x \cdot \Delta t \geq \frac{h}{4\pi}$$

$$\Delta E \cdot \Delta t \geq \frac{h}{4\pi}$$

$\Delta E \longrightarrow$ uncertainty in energy

$\Delta t \longrightarrow$ uncertainty in time



In terms of uncertainty in energy ΔE , and uncertainty in time Δt , this principle is written as,

$$\Delta E \cdot \Delta t \geq \frac{h}{4\pi}$$



Heisenberg replaced the concept of definite orbits by the concept of probability.

Ex.33 Why electron cannot exist inside the nucleus according to Heisenberg's uncertainty principle ?

Sol. Diameter of the atomic nucleus is of the order of 10^{-15} m

The maximum uncertainty in the position of electron is 10^{-15} m.

Mass of electron = 9.1×10^{-31} kg.

$$\Delta x \cdot \Delta p = \frac{h}{4\pi}$$

$$\Delta x \times (m \cdot \Delta v) = h/4\pi$$

$$\Delta v = \frac{h}{4\pi} \times \frac{1}{\Delta x \cdot m} = \frac{6.63 \times 10^{-34}}{4 \times \frac{22}{7}} \times \frac{1}{10^{-15} \times 9.1 \times 10^{-31}}$$

$$\Delta v = 5.80 \times 10^{10} \text{ ms}^{-1}$$

This value is much higher than the velocity of light and hence not possible.

Ex.34 If an electron is to be located within 10 pm what will be uncertainty in its velocity ?

Ans. $6 \times 10^6 \text{ m s}^{-1}$

Sol. $\Delta x \times m \Delta V = \frac{h}{4\pi}$

$$10 \times 10^{-12} \times 9.1 \times 10^{-31} \times \Delta V = \frac{6.6 \times 10^{-34}}{4 \times 3.14}$$

$$\Delta V = 6 \times 10^{-6} \text{ ms}^{-1}.$$

Ex.35 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. The uncertainty in the speed is 2%, i.e., $45 \times \frac{2}{100} = 0.9 \text{ m s}^{-1}$.

Using the equation, $\Delta x = \frac{h}{4\pi m \Delta v} = \frac{6.626 \times 10^{-34}}{4 \times 3.14 \times 40 \times 10^{-3} (0.9 \text{ ms}^{-1})} = 1.46 \times 10^{-33} \text{ m}$

This is nearly $\sim 10^{18}$ times smaller than the diameter of a typical atomic nucleus. As mentioned earlier for large particles, the uncertainty principle sets no meaningful limit to the precision of measurements.

Ex.36 What should be the uncertainty in position if uncertainty in momentum is 1×10^{-2} g cm/sec. and value of h is 6.6252×10^{-34} Joule sec. ?

(A) 1.054×10^{-22} m (B) 1.054×10^{-25} m (C) 0.525×10^{-27} m (D) 1.054×10^{-32} m

Sol. Given that

$$\Delta p = 1 \times 10^{-2} \text{ g cm/sec.} = 1 \times 10^{-7} \text{ kg m/sec.}$$

$$h = 6.6252 \times 10^{-34} \text{ Joule sec.}$$

$$\Delta x \times \Delta p = \frac{h}{4\pi} \quad \therefore \quad \Delta x = \frac{h}{4\pi \times \Delta p}$$

$$\text{or} \quad \Delta x = \frac{6.6252 \times 10^{-34}}{4 \times 3.14 \times 10^{-7}} = 0.525 \times 10^{-27} \text{ m}$$

Ex.37 If uncertainty in position of an e^- is same as the Δx of He atom. If Δp of e^- is 32×10^5 then find Δp in He atom.

Sol. $\Delta x \times \Delta p = \frac{h}{2\pi}$

Since Δx is same for both.

therefore Δp will be same by

$$\frac{\Delta x_e \times \Delta p_e \geq \frac{h}{4\pi}}{\Delta x_{(\text{He})} \times \Delta P_{\text{He}} \geq \frac{h}{4\pi}} = \frac{\pi P_e}{\Delta P_{\text{He}}} = 1$$

$$\therefore \Delta P_e = \Delta P_{\text{He}}$$

$$32 \times 10^5 = 32 \times 10^5$$

$$\Delta P_{\text{He}} = 32 \times 10^5$$

Ex.38 Calculate the uncertainty in the position of a particle when the uncertainty in momentum is

(a) 1×10^{-3} g cm sec $^{-1}$ (b) Zero.

Sol. Given

$$\Delta p = 1 \times 10^{-3} \text{ g cm sec}^{-1}$$

$$h = 6.62 \times 10^{-27} \text{ erg sec.}$$

$$\pi = 3.142$$

According to uncertainty principle

$$\Delta x \cdot \Delta p \geq \frac{h}{4\pi}$$

$$\begin{aligned}\text{So, } \Delta x &\geq \frac{h}{4\pi} \cdot \frac{1}{\Delta p} \\ &\geq \frac{6.62 \times 10^{-27}}{4 \times 3.142} \times \frac{1}{10^{-3}} \\ &= 0.527 \times 10^{-27} \text{ cm}\end{aligned}$$

(b) When the value of $\Delta p = 0$, the value of Δx will be infinite.

Ex.39 The uncertainty in position and velocity of a particle are 10^{-10} m and $5.27 \times 10^{-24} \text{ ms}^{-1}$ respectively. Calculate the mass of the particle ($h = 6.625 \times 10^{-34}$ Joule Sec.)

Sol. According to Heisenberg's uncertainty principle,

$$\begin{aligned}\Delta x \cdot m \Delta v &= \frac{h}{4\pi} \quad \text{or} \quad m = \frac{h}{4\pi \Delta x \cdot \Delta v} \\ &= \frac{6.625 \times 10^{-34}}{4 \times 3.143 \times 10^{-10} \times 5.27 \times 10^{-24}} = 0.099 \text{ kg}\end{aligned}$$

DO YOURSELF-5

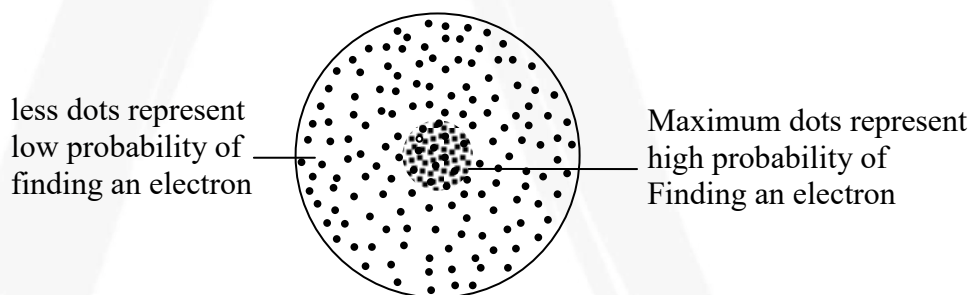
- A ball weighs 25 g moves with a velocity of 6.6×10^4 cm/sec then find out the De Broglie associated with it.
- Which of the following has least De Broglie if they have same velocity.
(A) e^- (B) p (C) CO_2 (D) SO_2
- The mass of a particle is 1 mg and its velocity is 4.5×10^5 cm per second. What should be the wavelength of this particle if $h = 6.652 \times 10^{-27}$ erg second.
(A) 1.4722×10^{-24} cm (B) 1.4722×10^{-29} cm
(C) 1.4722×10^{-32} cm (D) 1.4722×10^{-34} cm
- Which of the following should be the wavelength of an electron if its mass is 9.1×10^{-31} kg and its velocity is 1/10 of that of light and the value of h is 6.6252×10^{-24} joule second?
(A) 2.446×10^{-7} metre (B) 2.246×10^{-9} metre
(C) 2.246×10^{-11} metre (D) 2.246×10^{-13} metre
- What should be the momentum (in gram cm per second) of a particle if its De Broglie wavelength is 1 Å and the value of h is 6.6252×10^{-27} erg second ?
(A) 6.6252×10^{-19} (B) 6.6252×10^{-21} (C) 6.6252×10^{-24} (D) 6.6252×10^{-27}

6. Calculate the uncertainty in velocity of a cricket ball of mass 150 g if the uncertainty in its
7. 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 6.6252×10^{-34} kg m²/sec.?
 (A) 3.746×10^{-26} (B) 3.746×10^{-30} (C) 3.746×10^{-34} (D) 3.746×10^{-36}
8. What should be the uncertainty in the velocity of an electron if the uncertainty in its position is 0.005 nm, the mass of electron is 9.109×10^{-31} kg and the value of h is 6.6252×10^{-34} joule/second?
 (A) 2.316×10^5 (B) 1.158×10^7 (C) 2.316×10^9 (D) 2.316×10^{11}
9. What should be the uncertainty in velocity of a particle of 1 kg mass if uncertainty in position is 1 Å and the value of h is 6.6252×10^{-34} Joule sec.?
 (A) 1.055×10^{-22} (B) 1.055×10^{22} (C) 5.25×10^{-25} (D) 1.055×10^{24}

3. Orbital :

An orbital may be defined as the region of space around the nucleus where the probability of finding an electron is maximum (90% to 95%)

Orbitals do not define a definite path for the electron, rather they define only the probability of the electron being in various regions of space around the nucleus.



3.1 Difference between orbit and orbital's

Orbit

1. It is well defined circular path followed nucleus by revolving electrons around the nucleus found
2. It represents planar motion of electron
3. The maximum **number** of electron in an moreorbits is $2n^2$ where n stands for **number** of orbit.

Orbital's

1. It is the region of space around the where electron is most likely to be
2. It represents 3 dimensional motion of an electron around the nucleus.
3. Orbitals can not accomodate than 2 electrons.

4. Orbits are circular in shape.

5. Orbit are non directional in character.

Hence, they cannot explain shape of shape of molecules. molecules

6. Concept of well defined orbit is against Heisenberg's uncentainty principle.

4. Orbitals have different shape e.g. s-orbital is spherical, p - orbital is dumb- bell shaped.

5. Orbitals (except s-orbital) have directional character.

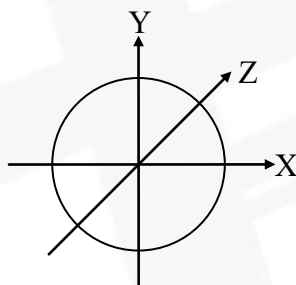
Hence, they can account for the

6. Concept of orbitals is in accordance with Heisenberg's principle

3.2 Shape of the orbitals :

Shape of the orbitals are related to the solutions of Schrodinger wave equation, and gives the space in which the probability of finding an electron is maximum.

s-orbital : Shape → spherical



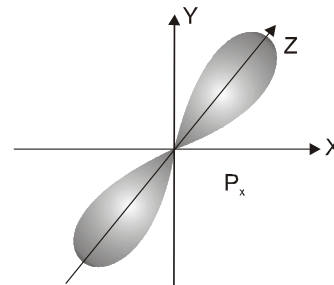
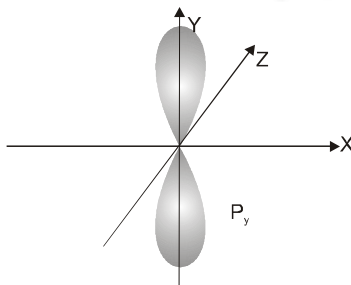
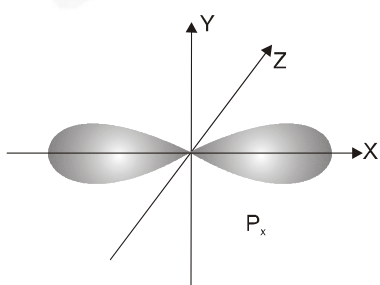
s-orbital is non directional and it is closest to the nucleus, having lowest energy.

s-orbital can accomodate maximum **number** of two electrons.

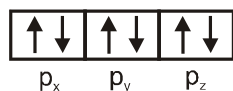


p-orbital : Shape → dumb bell

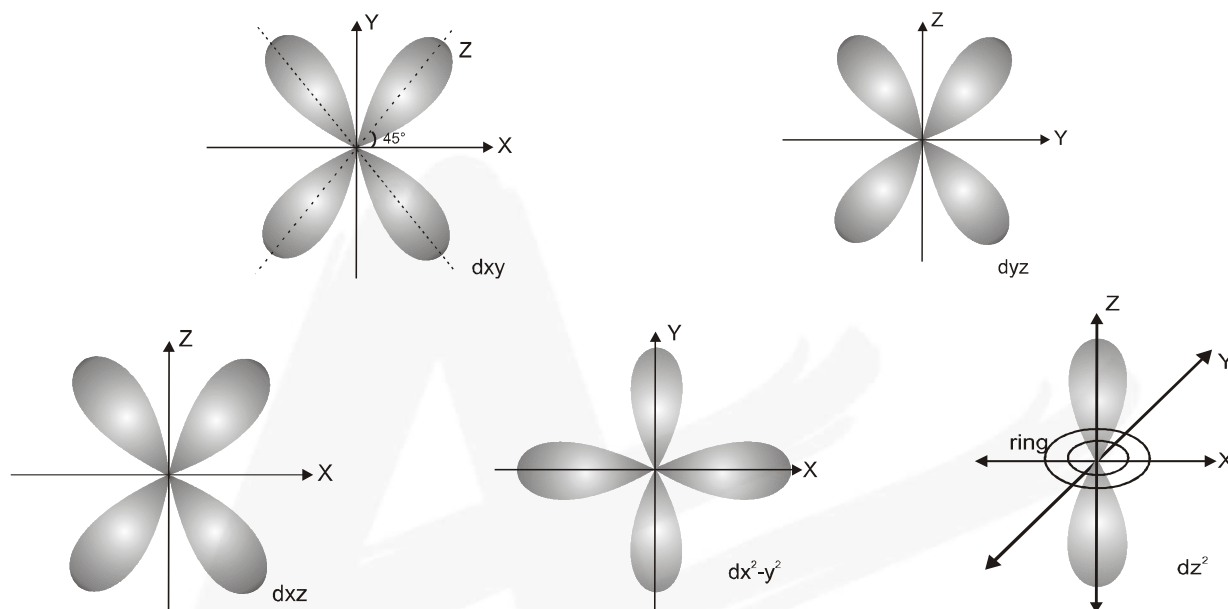
Dumb bell shape consists of two lobes which are separated by a region of zero probability called node.



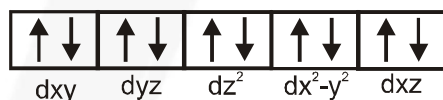
p - subshell can accommodate maximum **number** of six electrons.



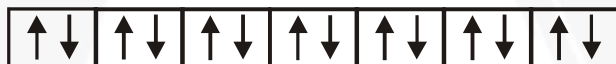
d-Orbital : Shape \rightarrow double dumb bell



d - subshell can accommodate maximum **number** of 10 electrons.



f-orbital : Shape leaf like



f - subshell can accommodate maximum **number** of 14 electrons.

3.4 QUANTUM NUMBERS :

The set of four numbers required to define an electron completely in an atom are called quantum numbers. The first three have been derived from Schrodinger wave equation.

(I) Principal quantum number (n) :

It describes the size of the electron wave and the total energy of the electron. It has integral values 1, 2, 3, 4, etc., and is denoted by K, L, M, N., etc.

- * Number of subshell present in n^{th} shell = n

n	subshell
1	s
2	s, p
3	s, p, d
4	s, p, d, f

- * Number of orbitals present in n^{th} shell = n^2 .
- * The maximum number of electrons which can be present in a principal energy shell is equal to $2n^2$.
No energy shell in the atoms of known elements possesses more than 32 electrons.
- * Angular momentum of any orbit = $\frac{nh}{2\pi}$

(II) Azimuthal quantum number (ℓ) :

It describes the shape of electron cloud and the number of subshells in a shell.

- * It can have values from 0 to $(n - 1)$

value of ℓ	subshell
0	s
1	p
2	d
3	f

- * Number of orbitals in a subshell = $2\ell + 1$
- * Maximum number of electrons in particular subshell = $2 \times (2\ell + 1)$
- * Orbital angular momentum $L = \frac{h}{2\pi} \sqrt{\ell(\ell+1)} = \hbar \sqrt{\ell(\ell+1)} \quad \left[\hbar = \frac{h}{2\pi} \right]$

i.e. Orbital angular momentum of s orbital = 0, Orbital angular momentum of p orbital = $\sqrt{2} \frac{h}{2\pi}$,

$$\text{Orbital angular momentum of d orbital} = \frac{\sqrt{6}h}{2\pi}$$

(III) Magnetic quantum number (m) :

It describes the orientations of orbitals with respect to standard set of coordinate axes. It can have values from $-\ell$ to $+\ell$ including zero, i.e., total $(2\ell + 1)$ values. Each value corresponds to an orbital. s-subshell has one orbital, p-subshell three orbitals (p_x , p_y and p_z), d-subshell five orbitals (d_{xy} , d_{yz} , d_{zx} , $d_{x^2-y^2}$, d_{z^2}) and f-subshell has seven orbitals.

- * The total number of orbitals present in a main energy level is ' n^2 '.

(IV) Spin quantum number (s) :

It describes the spin of the electron. It has values $+1/2$ and $-1/2$. signifies clockwise spinning and anticlockwise spinning.

Doublets & triplets are seen in multi electron system which made it evident that there must be some other energy level too than predicted by n , ℓ and m , it was later found to be s .

$$* \quad \text{Spin magnetic moment } \mu_s = \frac{eh}{2\pi mc} \sqrt{s(s+1)} \quad \text{or} \quad \mu = \sqrt{n(n+2)} \text{ B.M.}$$

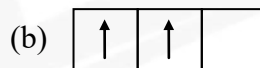
(n = number of unpaired electrons)

$$* \quad \text{It represents the value of spin angular momentum which is equal to } \frac{h}{2\pi} \sqrt{s(s+1)}$$

$$* \quad \text{Maximum spin of atom} = \frac{1}{2} \times \text{Number of unpaired electron.}$$

*** SPIN MULTIPLICITY**

It is given by $2S + 1$ where S is the total spin.



$$\text{For (a), } S = +\frac{1}{2} - \frac{1}{2} = 0$$

$$\text{Spin multiplicity} = 2S + 1 = 0 + 1 = 1 \text{ (singlet)}$$

$$\text{For (b), } S = +\frac{1}{2} + \frac{1}{2} = 1$$

$$\text{Spin multiplicity} = 2S + 1 = 2 \times 1 + 1 = 3 \text{ (triplet)}$$

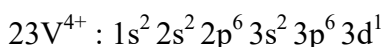
Ex.40 A compound of vanadium has a magnetic moment of 1.73 BM work out the electronic configuration of the vanadium in the compound.

Sol. Magnetic moment = $\sqrt{n(n+2)}$

Where n is number of unpaired electrons

$$\therefore 1.73 = \sqrt{n(n+2)} \quad \text{or} \quad (1.73)^2 = n^2 + 2n, n = 1$$

Vanadium atom must have the unpaired electron and thus its configuration is :



3.5 Electronic configuration :**(I) Aufbau principle :**

Aufbau is a German word meaning building up. The electrons are filled in various orbitals in order of their increasing energies. An orbital of lowest energy is filled first. The sequence of orbitals in order of their increasing energy is :

1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 5f, 6d,

The energy of the orbitals is governed by $(n + \ell)$ rule.

' $n + \ell$ ' Rule :

The relative order of energies of various sub-shell in a multi electron atom can be predicated with the help of ' $n + \ell$ ' rule

- The sub-shell with lower value of $(n + \ell)$ has lower energy and it should be filled first.

eg. 3d 4s
 $(n + \ell) = 3 + 2 = 5$ $(n + \ell) = 4 + 0 = 4$

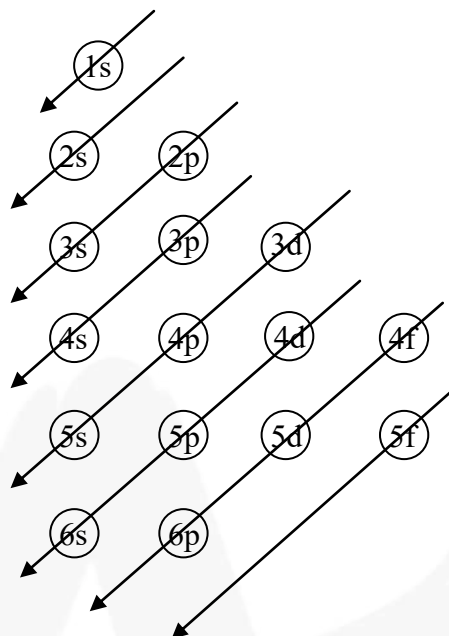
Since, $(n + \ell)$ value of 3d is more than 4s therefore, 4s will be filled before 3d.

- If two sub-shell has same value of $(n + \ell)$ then the sub-shell with lower value of n has lower energy and it should be filled first.

eg. 3d 4p
 $(n + \ell) = 3 + 2 = 5$ $(n + \ell) = 4 + 1 = 5$

3d is filled before 4p.

MEMORY MAP :



(II) Pauli's exclusion principle :

No two electrons in an atom can have the same set of all the four quantum numbers, i.e., an orbital cannot have more than 2 electrons and the three quantum numbers (principal, azimuthal and magnetic) at the most may be same but the fourth must be different, i.e. their spins must be in opposite directions.



(III) Hund's rule :

No electron pairing takes place in the orbitals in a sub - shell until each orbital is occupied by one electron with parallel spin. Exactly half filled and fully filled orbitals are observed to be more stable, i.e., p^3 , p^6 , d^5 , d^{10} , f^7 and f^{14} configuration are most stable probably because of the following reasons :

- (i) relatively small shielding
- (ii) larger exchange energy
- (iii) smaller coulombic repulsion energy.

Ex.41 Write the electronic configuration and find the **number** of unpaired electrons as well as total spin for the following atoms :

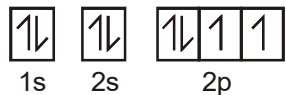
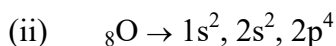
- (i) ${}_6\text{C}$ (ii) ${}_8\text{O}$ (iii) ${}_{15}\text{P}$ (iv) ${}_{21}\text{Sc}$ (v) ${}_{26}\text{Fe}$ (vi) ${}_{10}\text{Ne}$

Sol. (i) ${}_6\text{C} \rightarrow 1s^2, 2s^2, 2p^2$



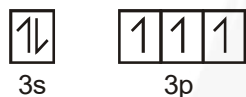
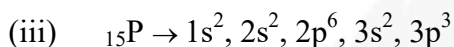
Number of unpaired electrons $\rightarrow 2$.

$$\text{Total spin} = \frac{+2}{2} \text{ or } \frac{-2}{2}$$



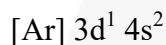
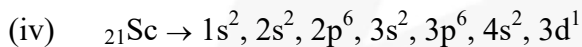
\therefore **Number** of unpaired electrons = 2

$$\text{Total spin} = \frac{+2}{2} \text{ or } \frac{-2}{2}$$



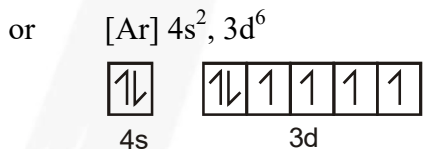
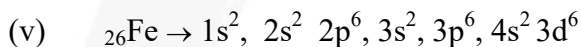
\therefore **Number** of unpaired electrons = 3

$$\text{Total spin} = \frac{+3}{2} \text{ or } \frac{+3}{2}$$



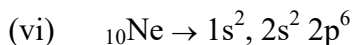
\therefore **Number** of unpaired electrons = 1

$$\therefore \text{Total spin} = \frac{+1}{2} \text{ or } \frac{-1}{2}$$



Number of unpaired electrons = 4

$$\therefore \text{Total spin} = \frac{+4}{2} \text{ or } \frac{-4}{2}$$



Number of unpaired electrons = 0

$$\text{Total spin} = 0$$

Ex.42 Write down the four quantum numbers for fifth and sixth electrons of carbon atom.

Sol. ${}_6\text{C} : 1s^2, 2s^2 2p^2$

$$\text{fifth electron} : n = 2 \quad \ell = 1 \quad m = -1 \text{ or } +1 \quad s = +\frac{1}{2} \text{ or } -\frac{1}{2}$$

$$\text{sixth electron} : n = 2 \quad \ell = 1 \quad m = 0 \quad s = +\frac{1}{2} \text{ or } -\frac{1}{2}$$

Ex.43 Calculate total spin, magnetic moment for the atoms having at. **number** 7, 24 and 36.

Sol. The electronic configuration are

$${}_7\text{N} : 1s^2, 2s^2 2p^3 \quad \text{unpaired electron} = 3$$

$${}_{24}\text{Cr} : 1s^2, 2s^2 2p^6, 3s^2 3p^6 3d^5, 4s^1 \quad \text{unpaired electron} = 6$$

$${}_{36}\text{Kr} : 1s^2, 2s^2 2p^6, 3s^2 3p^6 3d^{10}, 4s^2 4p^6 \quad \text{unpaired electron} = 0$$

\therefore Total spin for an atom $= \pm 1/2 \times \text{number of unpaired electron}$

For ${}_7\text{N}$, it is $= \pm 3/2$; For ${}_{24}\text{Cr}$, it is $= \pm 3$; For ${}_{36}\text{Kr}$, it is $= 0$

$$\text{Also magnetic moment} = \sqrt{n(n+2)}$$

$$\text{For } {}_7\text{N}, \text{ it is } = \sqrt{15}; \text{ For } {}_{24}\text{Cr}, \text{ it is } = \sqrt{48}; \text{ For } {}_{36}\text{Kr}, \text{ it is } = \sqrt{0}$$

- Electronic configurations of heavier elements (beyond $Z = 56$) deviate a little from the order mentioned previously. These are listed below :

Lanthanides	La ($Z = 57$)	:	$[\text{Xe}]6s^2 5d^1$ (not $4f^1$)
	Ce ($Z = 58$)	:	$[\text{Xe}]6s^2 5d^1 4f^1$
	Pr ($Z = 59$)	:	$[\text{Xe}]6s^2 5d^1 4f^2$
Actinides	Ac ($Z = 89$)	:	$[\text{Rn}]7s^2 6d^1$ (not $5f^1$)
	Th ($Z = 90$)	:	$[\text{Rn}]7s^2 6d^1 5f^1$
	Pa ($Z = 91$)	:	$[\text{Rn}]7s^2 6d^1 5f^2$
Beyond $Z = 103$	$Z = 104$:	$[\text{Rn}]5f^{14} 6d^2 7s^2$
	$Z = 105$:	$[\text{Rn}]5f^{14} 6d^3 7s^2$
	$Z = 106$:	$[\text{Rn}]5f^{14} 6d^4 7s^2$
	$Z = 112$:	$[\text{Rn}]5f^{14} 6d^{10} 7s^2$

❑ EXCEPTIONS : Stability of Half Filled and Completely Filled Orbitals

Cu has 29 electrons. its expected electronic configuration is $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 3d^9$. But a shift of one electron from lower energy 4s orbital to higher energy 3d orbital will make the distribution of electron symmetrical and hence will impart more stability.

Thus the electronic configuration of Cu is $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^1, d^{10}$

Fully filled and half filled orbital are more stable.

- (1) ${}_{24}\text{Cr} = [\text{Ar}] 4s^2, 3d^4$ (Not correct)
 $[\text{Ar}] 4s^1, 3d^5$ {correct : as d^5 (half filled) configuration is more stable than d^4 configuration}
- (2) ${}_{29}\text{Cu} = 4s^2, 3d^9$ (Not correct)
 $[\text{Ar}] 4s^1, 3d^{10}$ {correct : as d^{10} (full filled) configuration is more stable than d^9 configuration}.

Ex.44 Which of the following is the ground state electronic configuration of nitrogen :-

- (A) $\boxed{\uparrow\downarrow} \quad \boxed{\uparrow\downarrow} \quad \boxed{\uparrow} \quad \boxed{\uparrow} \quad \boxed{\uparrow}$ (B) $\boxed{\uparrow\downarrow} \quad \boxed{\uparrow\downarrow} \quad \boxed{\uparrow} \quad \boxed{\downarrow} \quad \boxed{\uparrow}$
- (C) $\boxed{\uparrow\downarrow} \quad \boxed{\uparrow\downarrow} \quad \boxed{\uparrow} \quad \boxed{\downarrow} \quad \boxed{\downarrow}$ (D) $\boxed{\uparrow\downarrow} \quad \boxed{\uparrow\downarrow} \quad \boxed{\downarrow} \quad \boxed{\downarrow} \quad \boxed{\downarrow}$

Sol. In (A) and (D), the unpaired electrons have spin in the same direction.

So, (A) and (D) are the correct answer.

Ex.45 Select the wrong statement (s) from the following ?

- (A) If the value of $l = 0$, the electron distribution is spherical
 (B) The shape of the orbital is given by magnetic quantum number
 (C) Angular momentum of 1s, 2s, 3s electrons are equal
 (D) In an atom, all electrons travel with the same velocity

Sol. (B) is wrong because shape is given by azimuthal quantum number and magnetic quantum number tells the orientation. (D) is wrong because electrons in different shells travel with different velocities.

So, (A) and (C) are the correct answer.

Ex.46 For the energy levels in an atom, which one of the following statement/s is/are correct ?

- (A) There are seven principal electron energy levels
 (B) The second principal energy level can have four sub-energy levels and contain a maximum of eight electrons
 (C) The M energy level can have a maximum of 32 electrons.
 (D) The 4s sub-energy level is at a lower energy than the 3d sub-energy level.

Sol. (A) and (D) are true. (B) is wrong because for $n = 2$, $l = 0, 1$ (two sub-energy levels). (C) is wrong because M shell means $n = 3$. Maximum electrons it can have $= 2n^2 = 2 \times 3^2 = 18$
 So, (A) and (D) is the correct answer.

Ex.47 Which of the following statement (s) is (are) correct ?

- (A) The electronic configuration of Cr is $[\text{Ar}]3d^5, 4s^1$ (Atomic number of Cr = 24)
- (B) The magnetic quantum number may have a negative value
- (C) In silver atom 23 electrons have spin of one type and 24 of the opposite type (Atomic number of Ag = 47)
- (D) The oxidation state of nitrogen in HN_3 is -3

Sol. Only (D) is wrong because oxidation state of N in HN_3 is $-1/3$.

So, (A), (B) and (C) are the correct answer.

3.5 SCHRODINGER WAVE MECHANICAL MODEL :

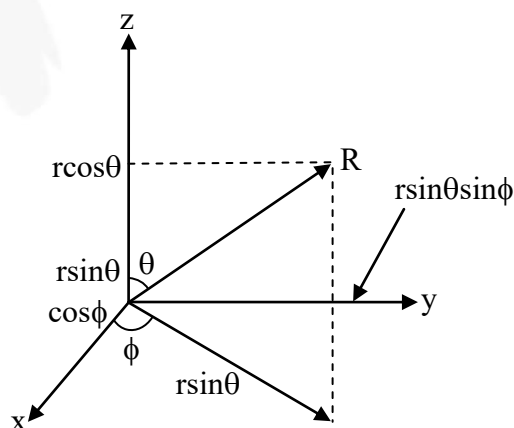
Ervin Schrodinger developed a model which is based on the particle and wave nature of the electron, known as Wave Mechanical Model of atom. The motion of electron around nucleus is round motion and may be considered to be analogous to the STANDING WAVES, the waves which are generated by plucking the stretched string. The amplitude of the standing wave is independent of time and is a function of the distance from one fixed end. The equation determines the behavior of the wave function that describes the wave like properties of subatomic system. It is solved to find the different energy levels of the system.

Schrodinger applied the equation to the hydrogen atom and predicted many of its properties with remarkable accuracy. The differential wave equation is as follows :

$$\frac{\delta^2 \psi}{\delta x^2} + \frac{\delta^2 \psi}{\delta y^2} + \frac{\delta^2 \psi}{\delta z^2} + \frac{8\pi^2 m}{h^2} (E - V) \psi = 0$$

where m is mass of electron, ψ is wave function, E is total energy of electron, V is potential energy and h is Planck's constant.

- Wave function has no actual physical meaning but the value of ψ^2 describes the probability distribution of an electron.
- When we solve the Schrodinger equation, it is observed that for some region of space, the value of ψ is positive and for other, it is negative. But the probability must be positive, so it is proper to use ψ^2 in place of ψ .
- The schrodinger equation can be written in terms of cartesian coordinates (x, y, z) or in terms of spherical polar coordinates (r, θ, ϕ). However due to spherical symmetry of atom, the wave functions are most simply expressed in terms a spherical polar coordinates. When Schrodinger wave equation in polar coordinates is solved for hydrogen atom the solution



obtained can be factorized into 2 separate parts, one being the function of r and other the function of θ and ϕ .

$$\psi(r, \theta, \phi) = R(r) \cdot X(\theta, \phi)$$

$R(r)$ = Radial part of wave function

$X(\theta, \phi)$ = Angular part of wave function

- ψ = Amplitude of wave
 ψ^2 = probability density \rightarrow It gives us probability of finding an electron at a point or per unit volume.
 Probability = $\psi^2 dv$
 R^2 = radial probability density,

Significance of ψ :

The wave function may be regarded as amplitude of electron wave expressed in terms of coordinates (x, y, z) or (r, θ, ϕ) . The wave function may have positive or negative values depending on the values of coordinates.

As such there is no physical significance of ψ .

* Significance of $(\psi)^2$:

In classical theory of electromagnetic radiation, the square of amplitude is proportional to the intensity of light. A very similar concept was suggested by MAX BORN in QUANTUM MECHANICS according to which the square of function ψ at any point is proportional to the probability of finding an electron at that point ψ^2 is known as PROBABILITY DENSITY and is always $^{+ve}$. The region of space in which there is maximum probability of finding an electron (say 90%) is termed as an orbital.

- $\psi_{(r)}$ i.e. radial part of wave function depends upon quantum number n and l and decides the size of an orbital.
- Angular part of wave function $\psi_{(\theta, \phi)}$, depends upon quantum numbers l and m and describes the shape of orbital.

For the sake of convenience the $\psi_{(r)}$ vs. r and $\psi_{(\theta, \phi)}$ vs. angle are plotted separately.

An atomic orbital is a one electron wave function $\Psi(r, \theta, \phi)$ obtained from the solution of the Schrodinger equation. The orbital wave function Ψ has no physical significance but its square (Ψ^2) has a physical significance it measures the electron probability density at a point in an atom.

3.5.1 Radial wave function (R) : In all cases R approaches zero as r approaches infinity. We find that there is a node in the 2s radial function. At the node the value of the radial function changes from positive to negative. In general, it has been found that ns-orbitals have (n-1) radial nodes and np-orbitals have (n-2) radial nodes etc.

The radial functions $R(r)$ are products of an exponential function with a polynomial in the dimensionless variable r/a_0 . Their functional form depends on the quantum numbers n and l .

The first few normalized radial functions $R(r)$ are as follows:

$$n = 1, l = 0 \quad R_{10}(r) = 2 \left(\frac{1}{a_0} \right)^{3/2} e^{-r/a_0}$$

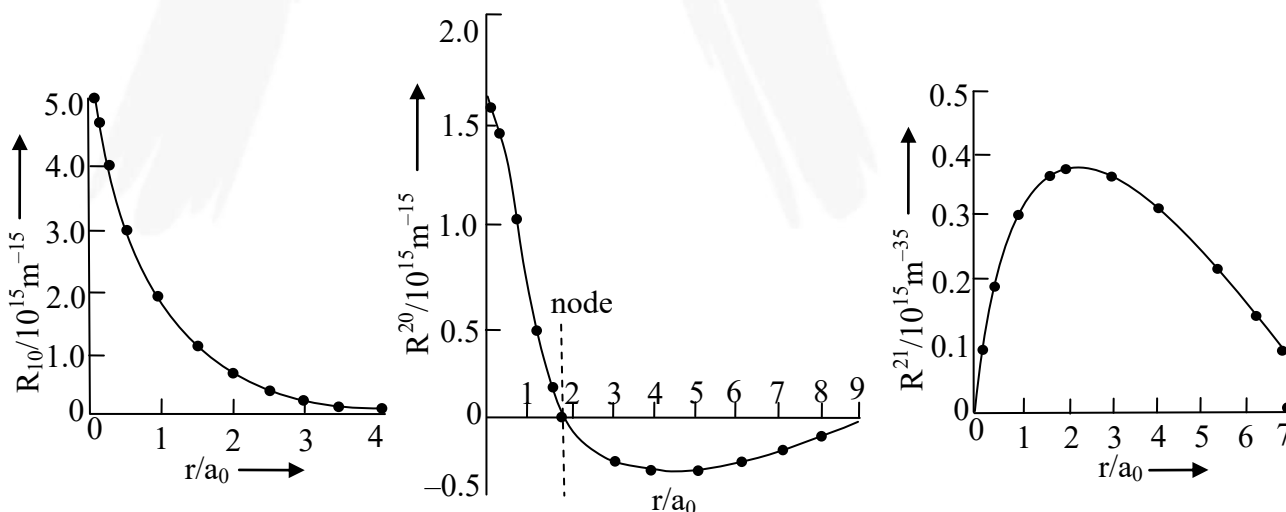
$$n = 2, l = 0 \quad R_{20}(r) = \frac{1}{\sqrt{8}} \left(\frac{1}{a_0} \right)^{3/2} \left(2 - \frac{r}{a_0} \right) e^{-r/2a_0}$$

$$n = 2, l = 1 \quad R_{21}(r) = \frac{1}{\sqrt{24}} \left(\frac{1}{a_0} \right)^{3/2} \frac{r}{a_0} e^{-r/2a_0}$$

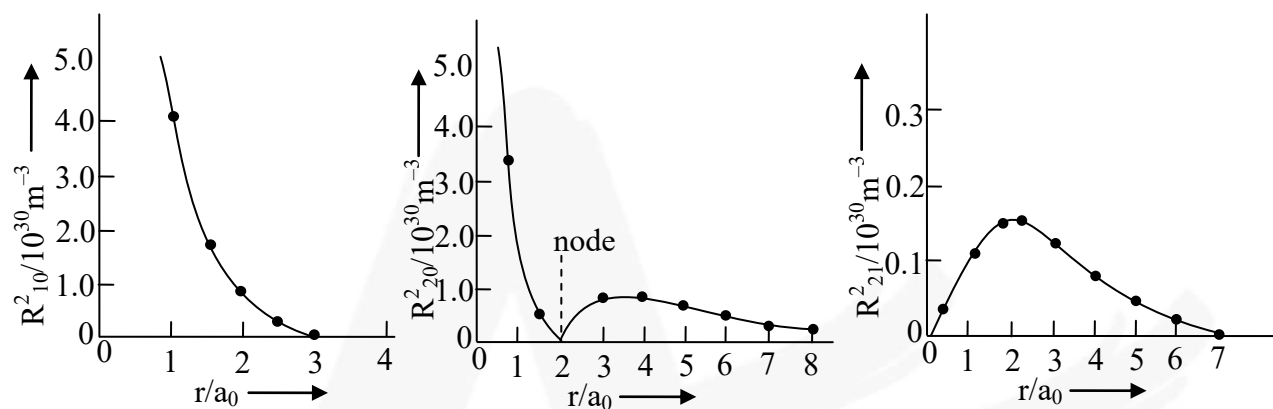
$$n = 3, l = 0 \quad R_{30}(r) = \frac{2}{81\sqrt{3}} \left(\frac{1}{a_0} \right)^{3/2} \left(27 - 18 \frac{r}{a_0} + 2 \frac{r^2}{a_0^2} \right) e^{-r/3a_0}$$

$$n = 3, l = 1 \quad R_{31}(r) = \frac{4}{81\sqrt{6}} \left(\frac{1}{a_0} \right)^{3/2} \left(6 \frac{r}{a_0} - \frac{r^2}{a_0^2} \right) e^{-r/3a_0}$$

$$n = 3, l = 2 \quad R_{32}(r) = \frac{4}{81\sqrt{30}} \left(\frac{1}{a_0} \right)^{3/2} \frac{r^2}{a_0^2} e^{-r/3a_0}$$

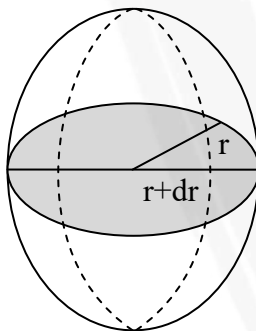


3.5.2 Radial Probability density (R^2) : The radial density R^2 gives the probability density of finding the electron at a point along a particular radius line. Plots in fig. (B) give useful information about probability density or relative electron density at a point as a function of radius. It may be noted that for s-orbitals the maximum electron density is at the nucleus while all other orbitals have zero electron density at the nucleus. Its zero value ($R^2 = 0$) indicates zero probability of finding an electron.



3.5.3 Radial probability function $4\pi r^2 R^2$ [Radial probability] : Since the atoms have spherical symmetry, It is more useful to discuss the probability of finding the electron in a spherical shell between the spheres of radius $(r + dr)$ and r .

The volume of the shell is equal to $\frac{4}{3}\pi(r + dr)^3 - \frac{4}{3}\pi r^3 = 4\pi r^2 dr$.



dr is very very less

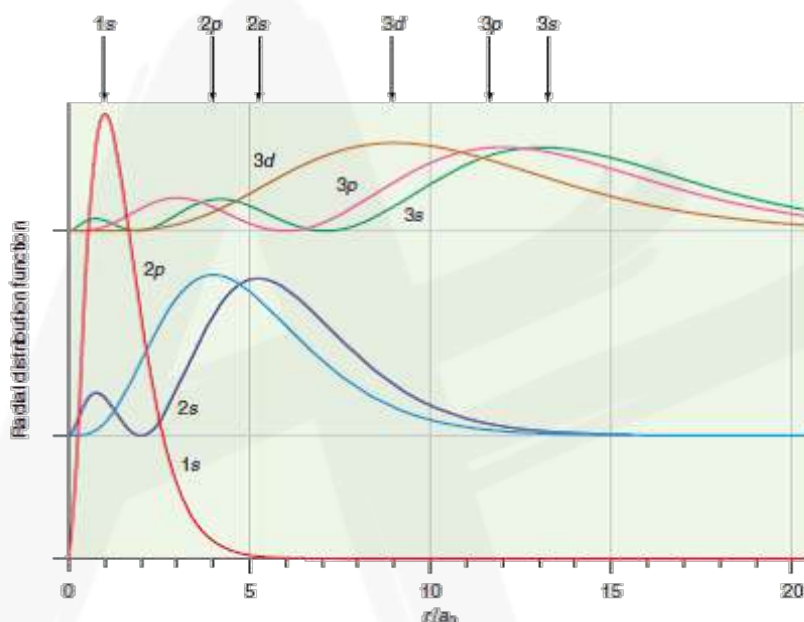
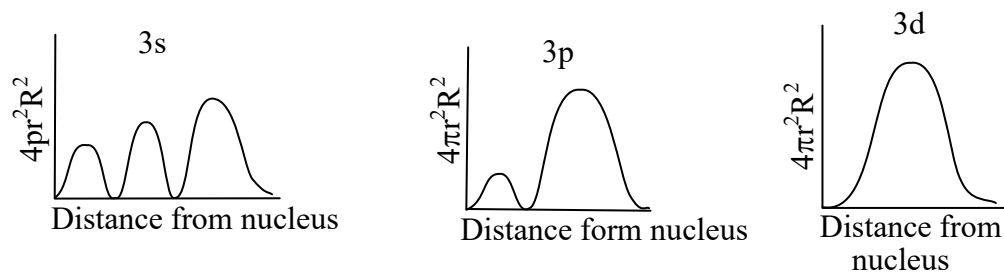
$$\text{volume} = \frac{4}{3}\pi((r + dr)^3 - r^3) \text{ shell}$$

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

$$dr^2 \text{ and } dr^3 \text{ are neglected} = \frac{4}{3}\pi(3r^2 dr) = 4\pi r^2 dr$$

$$\text{Radial probability in given shell} = R^2 \cdot 4\pi r^2 dr$$

The probability of finding an electron at a distance r from the nucleus in all the direction is called radial probability function (RPF).



This probability which is independent of direction is called radial probability and is equal to $[4\pi r^2 dr R^2]$. It gives the probability of finding the electron at a distance r from the nucleus regardless of direction.

Angular part of wave function :

$$z = r \cos \theta$$

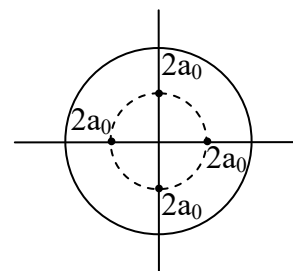
$$y = r \sin \theta \sin \phi$$

$$x = r \sin \theta \cos \phi$$

RADIAL NODES : Points at which the probability of finding an electron is zero is known as radial nodes.

Number of radial nodes = $n - l - 1$

Electron cannot be present at $2a_0$ distance from nucleus. If we join all $2a_0$ points to form a sphere, we can say that electron cannot be present on surface of sphere, however it may be present inside or outside. At

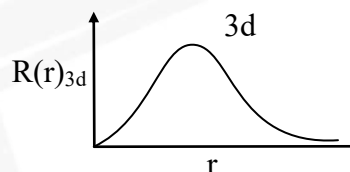
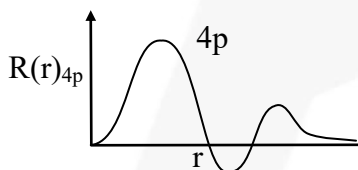
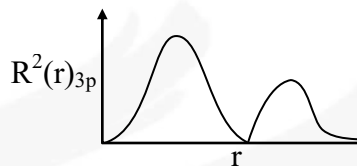
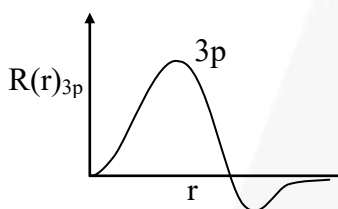
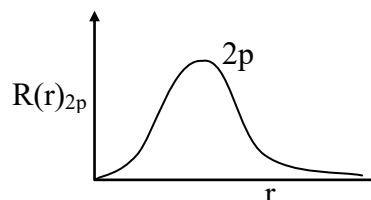


$2a_0$ distance probability of presence of electron is zero. Since a sphere is formed radial nodes are also called SPHERICAL NODES.

Radial nodes are spherical in shape also known as spherical nodes or nodal sphere.

❑ GRAPHS FOR P-ORBITALS :

$$R(r)_{2p} = \frac{1}{2\sqrt{6}} \left(\frac{1}{a_0} \right)^{\frac{3}{2}} \sigma e^{-\frac{\sigma}{2}}$$



ANTINODE POINT - Point at which probability of finding an electron is max.

❑ COMPARISON OF r_{\max} & r_{avg} FOR DIFFERENT ORBITALS :

Note : r_{avg} is always greater than r_{\max}

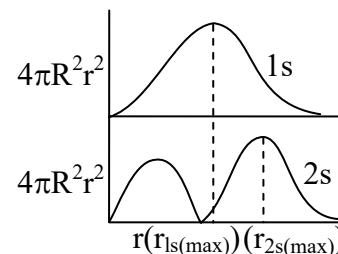
Case I - when l is same but n is different.

As value of n increases r_{\max} increases.

Peaks are numbered according to value of $(n - l)$.

As n increases r_{avg} increases if r_{avg} is more,

electron will be more away from nucleus.



- ❑ **PENETRATION POWER** : Penetration power of orbital is a measure of its closeness to the nucleus.

$$1s > 2s > 3s$$

Case II - When 'n' is same but 'l' different.

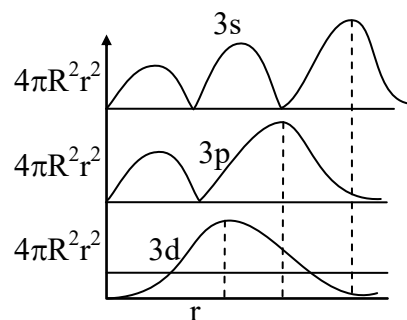
As value of 'l' increases, r_{avg} increases

As value of 'l' increases, r_{max} decreases

$$l \uparrow \quad r_{\text{max.}} \downarrow$$

$$l \uparrow \quad r_{\text{avg.}} \uparrow$$

Closeness to nucleus - $3s > 3p > 3d$

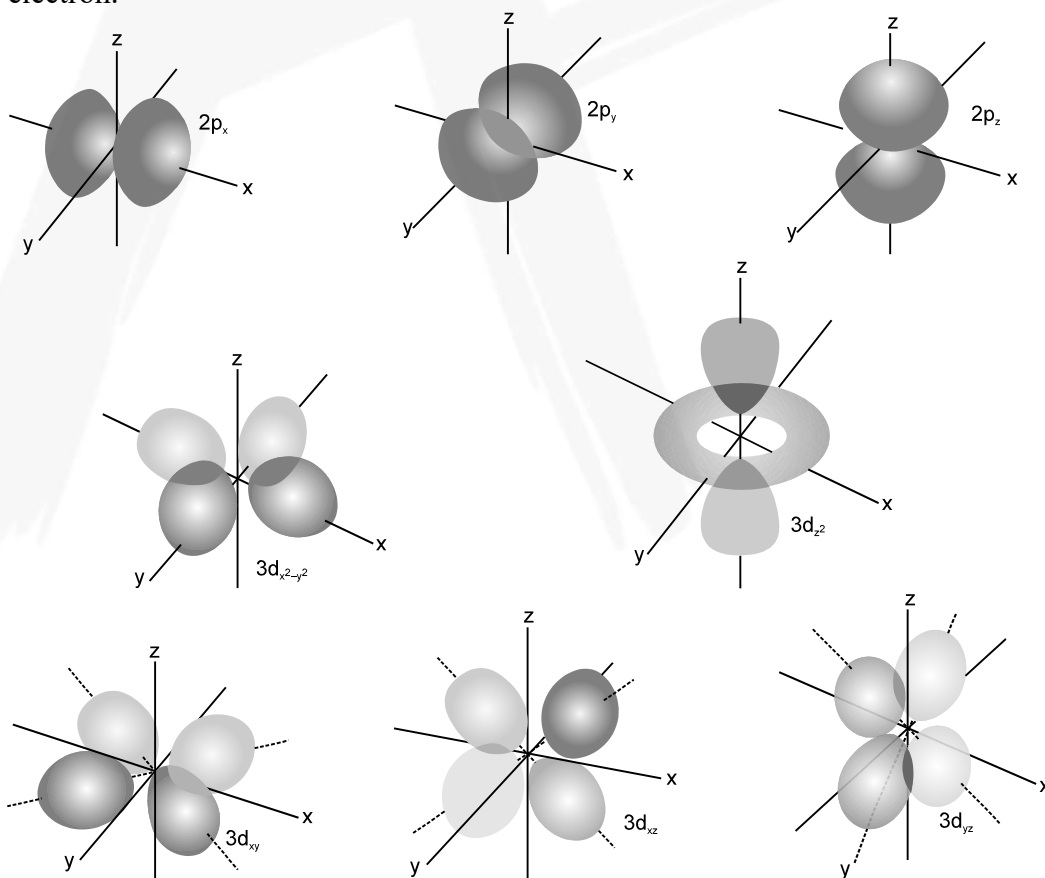


- ❑ **SHAPE OF ANGULAR NODE** :

The important point of the solution of this equation is that it provides a set of numbers called quantum numbers. Quantum numbers are required to describe the distribution of electrons in atoms. Quantum numbers derived from the solution of Schrodinger equation are called principal quantum number, azimuthal quantum number and magnetic quantum number. These quantum numbers are used to describe the atomic orbitals.

Orbital : The locations in space at which the probability of finding the electron is maximum.

Node and Nodal Plane : Node represents the region where probability of finding an electron is zero (i.e., ψ and $\psi^2 = 0$). Similarly nodal plane represents the plane having zero probability of finding electron.



The 3d-orbitals of the hydrogen atom. Note the relation between the labeling of the d-orbitals and their orientations in space.

Nodes are of two types : (a) Radial node (b) Angular node

A radial node is the spherical region around nucleus having ψ and ψ^2 equal to zero. An orbital having higher number of nodes has more energy.

Calculation of number of nodes :

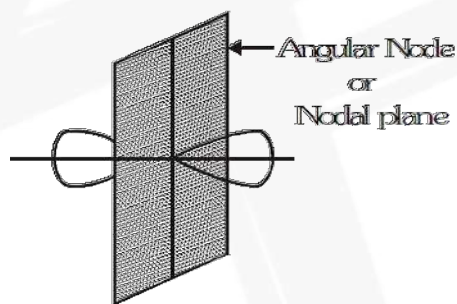
- * Radial nodes = $n - \ell - 1$,
- * Angular nodes = ℓ ,
- * Total nodes = $n - 1$, where n and ℓ are principal and azimuthal quantum numbers.

e.g. In 3p-orbital, Radial nodes = $3 - 1 - 1 = 1$ ($= n - \ell - 1$)

Angular nodes = 1 ($= \ell$)

Total nodes = 2 (one radial, one angular)

For P_x :



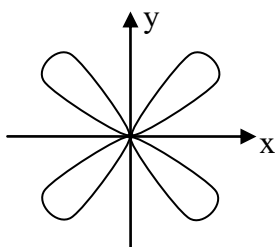
Angular node or nodal plane

$\therefore P_x \rightarrow yz$ plane

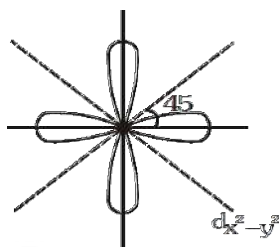
$P_y \rightarrow xz$ plane

$P_z \rightarrow xy$ plane

For d_{xy} :



- $\therefore d_{xy} \rightarrow xz \text{ and } yz$
 $d_{yz} \rightarrow xz \text{ and } xy$
 $d_{zx} \rightarrow xy \text{ and } yz$



We cannot predict the designation of angular nodes but can be said that at an angle of 45° with axis.

DO YOURSELF-6

- Two electrons A and B in an atom have the following set of quantum numbers; what is true for A and B :
 For A; $n = 3, \ell = 2, m = -2, s = \pm \frac{1}{2}$
 For B; $n = 3, \ell = 0, m = 0, s = \pm \frac{1}{2}$
 (A) A and B have same energy (B) A has more energy than B
 (C) B has more energy than A (D) A and B represent the same electron
- Which of the following statements is incorrect with respect to V^{4+} ion : [More than one option may be correct]
 (A) Maximum possible number of electrons with clockwise spin and $m = 0$ is 11.
 (B) The correct set of quantum numbers for the unpaired electron is $n = 4, \ell = 0, m = 0$.
 (C) Total number of electrons in orbitals with one radial node and $m_s = 1/2$ is 4.
 (D) Total number of orbitals having $\ell = 0$ is 6.
- A d-block element has total spin value of $+3$ or -3 then the magnetic moment of the element is approximately:
 (A) 2.83 B.M. (B) 3.87 B.M. (C) 5.9 B.M. (D) 6.93 B.M.
- The correct order of the maximum spin of $[_{25}\text{Mn}^{4+}, _{24}\text{Cr}^{3+}, _{26}\text{Fe}^{3+}]$ is :
 (A) $\text{Fe}^{3+} > \text{Cr}^{3+} = \text{Mn}^{4+}$ (B) $\text{Fe}^{3+} = \text{Cr}^{3+} > \text{Mn}^{4+}$
 (C) $\text{Cr}^{3+} = \text{Mn}^{4+} > \text{Fe}^{3+}$ (D) $\text{Fe}^{3+} > \text{Mn}^{4+} > \text{Cr}^{3+}$
- Orbital angular momentum of an electron is $\sqrt{3} \frac{h}{\pi}$ then the number of orientations of this orbital in space are :
 (A) 3 (B) 5 (C) 7 (D) 9

MEMORY TIPS

- Frequency, $\nu = \frac{c}{\lambda}$
- Energy/photon, $E = h\nu = \frac{hc}{\lambda}$
Also, $E = \frac{12375}{\lambda} \text{ eV}$, if λ is in Å
- Electronic energy change during transition, $\Delta E = E_{n_2} - E_{n_1}$
 $n_2 > n_1$, emission spectra if electron jumps from n_2 to n_1 shell and absorption spectra if electron excites from n_1 to n_2 shell.
- Radius of nth Bohr orbit of H atom, $r_n = \frac{n^2 h^2}{4\pi^2 m e^2 K}$ (where $K = 9 \times 10^9$)
 r_1 for H = 0.529 Å ; r_n for H like atom $r_n = 0.529 \times \frac{n^2}{Z} \text{ Å}$
- Velocity of electron in nth Bohr orbit of H atom, $v = \frac{2\pi K Z e^2}{n h}$
 $v = 2.18 \times 10^8 \frac{Z}{n} \text{ cm / sec.}$
- Energy of electron in nth Bohr orbit of H atom, $E = \frac{2\pi^2 m Z^2 e^4 K^2}{n^2 h^2}$
where $n = 1, 2, 3, \dots$
 $[E = -13.6 \times \frac{Z^2}{n^2} \text{ kcal/mole (1 cal = 4.18 J)}]$
 E_1 for H = $-21.72 \times 10^{-12} \text{ erg} = -13.6 \text{ eV}$, E_1 for H like atom = E_1 for H $\times Z^2$
- Wavelength emitted during transition in H atom,
 $\frac{1}{\lambda} = R_H \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] = \frac{2\pi^2 m e^4}{ch^3} \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$ (in C.G.S.)
- Photoelectric effect $h\nu = w + \frac{1}{2} m u^2$ or $h\nu = \text{I.E.} + \text{K.E.}$
- Possible transitions for a jump from n_2 to $n_1 = \sum (n_2 - n_1)$
- Angular momentum of electron in an orbit = $n \cdot (h/2\pi)$

11. Angular momentum of electron in an orbital = $(nh/2\pi) \sqrt{\ell(\ell+1)}$
12. Total spin = $\pm \left(\frac{1}{2} \times n\right)$; where n is **number** of unpaired electrons.
13. Magnetic moment of an atom $\sqrt{n(n+2)}$ B.M.; where n is **number** of unpaired electrons.
14. Nodal planes : Radial nodes = $n - l - 1$, Angular nodes = l , Total nodes = $(n - l)$
15. de Broglie equation : $\lambda = \frac{h}{mu} = \frac{h}{\sqrt{2 \times \text{K.E.} \times m}}$
 where λ is wavelength, m is mass and u is velocity of particle.
16. Heisenberg uncertainty principle :

$$\Delta p \cdot \Delta x \geq \frac{h}{4\pi}$$

$$\Delta u \cdot \Delta x \geq \frac{h}{4\pi m}$$
 where Δp , Δu and Δx are uncertainties in momentum, velocity and position respectively.
 Planck's constant is h and m is mass of subatomic particle.

Rutherford Model

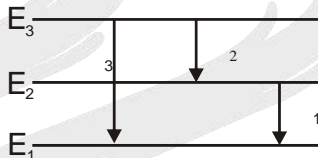
- The approximate size of the nucleus of ${}^{64}_{28}\text{Ni}$ is :
 (A) 3 fm (B) 4 fm (C) 5 fm (D) 2 fm
- Rutherford's alpha particle scattering experiment eventually led to the conclusion that
 (A) mass and energy are related
 (B) electrons occupy space around the nucleus
 (C) neutrons are buried deep in the nucleus
 (D) the point of impact with matter can be precisely determined

Plancks Quantum theory, No. pf photons

- 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
- A bulb of 40 W is producing a light of wavelength 620 nm with 80% of efficiency then the number of photons emitted by the bulb in 20 seconds are ($1\text{eV} = 1.6 \times 10^{-19}\text{ J}$, $hc = 12400\text{ eV Å}$)
 (A) 2×10^{18} (B) 10^{18} (C) 10^{21} (D) 2×10^{21}

Bohr's Model

- The ratio of the radii of two Bohr orbits of H-atoms is 4 : 1 what would be their nomenclature
 (A) K & L (B) L & K (C) N & L (D) B & C both
- Correct order of radius of the 1st orbit of H, He^+ , Li^{2+} , Be^{3+} is :
 (A) $\text{H} > \text{He}^+ > \text{Li}^{2+} > \text{Be}^{3+}$ (B) $\text{Be}^{3+} > \text{Li}^{2+} > \text{He}^+ > \text{H}$
 (C) $\text{He}^+ > \text{Be}^{3+} > \text{Li}^{2+} > \text{H}$ (D) $\text{He}^+ > \text{H} > \text{Li}^{2+} > \text{Be}^{3+}$
- In a certain electronic transition in the hydrogen atoms from an initial state (1) to a final state (2), the difference in the orbital radius ($r_1 - r_2$) is 24 times the first Bohr radius. Identify the transition.
 (A) $5 \rightarrow 1$ (B) $25 \rightarrow 1$ (C) $8 \rightarrow 3$ (D) $6 \rightarrow 5$
- The energy levels for ${}_Z\text{A}^{(Z-1)}$ can be given by :-
 (A) E_n for $\text{A}^{(Z-1)} = Z^2 \times E_n$ for H (B) E_n for $\text{A}^{(Z-1)} = Z \times E_n$ for H
 (C) E_n for $\text{A}^{(Z-1)} = \frac{1}{Z^2} \times E_n$ for H (D) E_n for $\text{A}^{(Z-1)} = \frac{1}{Z} \times E_n$ for H

9. If the potential energy (PE) of hydrogen electron is -3.02eV then in which of the following excited level is electron present :-
 (A) 1st (B) 2nd (C) 3rd (D) 4th
10. 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
11. 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) $(E_2 - E_1) = 1/4 (E_3 - E_2) = 1/9 (E_4 - E_3)$
12. The energy of H-atom in n^{th} orbit is E_n then energy in n^{th} orbit of singly ionized helium atom will be:
 (A) $4E_n$ (B) $E_n/4$ (C) $2E_n$ (D) $E_n/2$
13. In the following transition which statement is correct?
 (A) $E_3 - E_1 = E_3 - E_2 + E_2 - E_1$
 (B) $\lambda_3 = \lambda_1 + \lambda_2$
 (C) $\nu_3 = \nu_2 + \nu_1$
 (D) None
- 
14. 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 wavelengths 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) $\frac{2}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$
15. The binding energy of e^- in ground state of hydrogen atom is 13.6 eV . The energies required to eject out an electron from three lowest states of He^+ ion will be – (in eV)
 (A) 13.6, 10.2, 3.4 (B) 13.6, 3.4, 1.5 (C) 13.6, 27.2, 40.8 (D) 54.4, 13.6, 6
16. A single electron is revolving orbits a round nucleus a stationary ($z = 5$). The energy required to excite the electron from the third to the fourth Bohr orbit will be :-
 (A) 4.5 eV (B) 8.53 eV (C) 25 eV (D) 16.53 eV
17. A photon of energy 12.75 eV is completely absorbed by a hydrogen atom initially in ground state. The principal quantum number of the excited state is
 (A) 1 (B) 3 (C) 4 (D) ∞
18. A 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

19. Angular momentum in 2nd Bohr orbit of H-atom is x . Then find out angular momentum in 1st excited state of Li^{+2} :-
 (A) $3x$ (B) $9x$ (C) $x/2$ (D) x
20. In an atom, two electrons move round the nucleus in circular orbits of radii R and $4R$. The ratio of the time taken by them to complete one revolution is: (Consider Bohr model to be valid)
 (A) $1 : 4$ (B) $4 : 1$ (C) $1 : 8$ (D) $8 : 1$
21. The angular momentum of an electron in a given orbit is J , its kinetic energy will be :
 (A) $\frac{1}{2} \frac{J^2}{mr^2}$ (B) $\frac{Jv}{r}$ (C) $\frac{J^2}{2m}$ (D) $\frac{J^2}{2\pi}$
22. Given ΔH for the process $\text{Li(g)} \longrightarrow \text{Li}^{+3}(\text{g}) + 3e^-$ is 19800 kJ/mole & IE_1 for Li is 520 then IE_2 & IE_3 of Li are respectively (approx. value)
 (A) $7505, 11775$ (B) $520, 19280$
 (C) $11775, 19280$ (D) Data insufficient

Spectrum

23. The first Lyman transition in the hydrogen spectrum has $DE = 10.2 \text{ eV}$. The same energy change is observed in the second Balmer transition of :-
 (A) Li^{2+} (B) Li^+ (C) He^+ (D) Be^{3+}
24. 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) $4 \rightarrow 2$
25. The shortest wavelength of He^+ ion in Balmer series is x , then longest wavelength in the Paschen series of Li^{+2} is
 (A) $\frac{36x}{5}$ (B) $\frac{16x}{7}$ (C) $\frac{9x}{5}$ (D) $\frac{5x}{9}$
26. The ratio of difference in wavelengths of 1st and 2nd lines of Lyman series in H-like atom to difference in wavelength for 2nd and 3rd lines of same series is:
 (A) $2.5 : 1$ (B) $3.5 : 1$ (C) $4.5 : 1$ (D) $5.5 : 1$
27. 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) $3 : 16$
28. In a sample of H-atoms, electrons de-excite from a level ' n ' to 1. The total number of lines belonging to Balmer series are two. If the electrons are ionized from level ' n ' by photons of energy 13 eV . Then the kinetic energy of the ejected photoelectrons will be :

- (A) 12.15 eV (B) 11.49 eV (C) 12.46 eV (D) 12.63 eV
29. The value of $(n_2 + n_1)$ and $(n_2^2 - n_1^2)$ 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) $(9/32)R_H$ (B) $(32/9)R_H$ (C) $\frac{9}{32R_H}$ (D) $\frac{32}{9R_H}$
30. An atom has x energy level, then total number of lines in its spectrum are:-
- (A) $1 + 2 + 3 \dots (x + 1)$ (B) $1 + 2 + 3 \dots (x^2)$
 (C) $1 + 2 + 3 \dots (x - 1)$ (D) $(x + 1)(x + 2)(x + 4)$
31. In a sample of H-atoms, electron transits from 6th orbit to 2nd orbit in multi steps. Then total spectral lines (without Balmer series) will be :
- (A) 6 (B) 10 (C) 4 (D) 0
32. 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

Photoelectric Effect

33. A photon of energy $h\nu$ is absorbed by a free electron of a metal having work function $w < h\nu$. Then :
- (A) The electron is sure to come out
 (B) The electron is sure to come out with a kinetic energy $(h\nu - w)$
 (C) Either the electron does not come out or it comes with a kinetic energy $(h\nu - w)$
 (D) It may come out with a kinetic energy less than $(h\nu - w)$
34. Which of the following statement is false in the context of photoelectric effect ?
- (A) The kinetic energy of ejected electron is independent of the photointensity of a radiation.
 (B) The number of photoelectrons ejected depends upon the photointensity of the incident radiation.
 (C) The kinetic energy of the emitted electrons depends on the frequency of the incident radiation.
 (D) The kinetic energy of the emitted electrons depends on the photointensity of the incident radiation.
35. A beam of white light is dispersed into its wavelength components by a Quartz prism and falls on a thin sheet of potassium metal. What is the correct decreasing order of maximum kinetic energy of the electron emitted by the different light component.
- (A) blue > green > orange > yellow (B) violet > blue > orange > red
 (C) yellow > green > blue > violet (D) orange > yellow > blue > violet

36. A light source of wavelength λ illuminates a metal and ejects photo-electrons with $(K.E.)_{\max} = 1 \text{ eV}$. Another light source of wavelength $\frac{\lambda}{3}$, ejects photo-electrons from same metal with

$(K.E.)_{\max} = 4 \text{ eV}$. Find the value of work function ?

- (A) 1 eV (B) 2 eV (C) 0.5 eV (D) None of these
37. When a beam of photons of a particular energy was incident on a surface of a particular pure metal having work function = (40 eV), some emitted photoelectrons had stopping potential equal to 22 V, some had 12 V and rest had lower values. Calculate the wavelength of incident photons assuming that at least one photoelectron is ejected with maximum possible kinetic energy.

(A) 310 Å (B) 298 Å (C) 238 Å (D) 200 Å

38. Electromagnetic radiations having $\lambda = 310 \text{ Å}$ 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) $2.18 \times 10^6 \text{ m/s}$
(C) $2.18 \sqrt{2} \times 10^6 \text{ m/s}$ (D) $8.72 \times 10^6 \text{ m/s}$

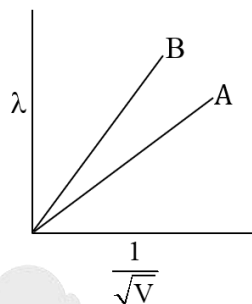
De-Broglie Hypothesis

39. 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
40. An electron in a hydrogen atom in its ground state absorbs energy equal to the ionisation energy of Li^{+2} . The wavelength of the emitted electron is:
- (A) $3.32 \times 10^{-10} \text{ m}$ (B) 1.17 Å (C) $2.32 \times 10^{-9} \text{ nm}$ (D) 3.33 pm
41. A particle X moving with a certain velocity has a de-Broglie wavelength of 1Å. If particle Y has a mass of 25% that of X and velocity 75% that of X, de-Broglie's wavelength of Y will be :
- (A) 3Å (B) 5.33 Å (C) 6.88 Å (D) 48Å
42. 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) $\lambda_\alpha < \lambda_e \gg \lambda_p$
43. An electron has kinetic energy $2.8 \times 10^{-23} \text{ J}$. de-Broglie wavelength will be nearly :- ($m_e = 9.1 \times 10^{-31} \text{ kg}$)
- (A) $9.28 \times 10^{-24} \text{ m}$ (B) $9.28 \times 10^{-7} \text{ m}$ (C) $9.28 \times 10^{-8} \text{ m}$ (D) $9.28 \times 10^{-10} \text{ m}$
44. What will be de-Broglie wavelength of an electron moving with a velocity of $1.2 \times 10^5 \text{ ms}^{-1}$:
- (A) $6.068 \times 10^{-9} \text{ m}$ (B) $3.133 \times 10^{-37} \text{ m}$ (C) $6.626 \times 10^{-9} \text{ m}$ (D) $6.018 \times 10^{-7} \text{ m}$

45. For a valid Bohr orbit, its circumference should be:

- (A) $n\lambda$ (B) $(n-1)\lambda$ (C) $>n\lambda$ (D) $<n\lambda$

46. De-Broglie wavelength of two particles A & B of same charge 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?



- (A) $M_A = M_B$ (B) $M_A > M_B$ (C) $M_A < M_B$ (D) $M_A \leq M_B$

47. An electron in a hydrogen like atom makes transition from a state in which its de-Broglie wavelength is λ_1 to a state where its de-Broglie wavelength is λ_2 then wavelength of photon (λ) generated will be

- (A) $\lambda = \lambda_1 - \lambda_2$ (B) $\lambda = \frac{4mc}{h} \left\{ \frac{\lambda_1^2 \lambda_2^2}{\lambda_1^2 - \lambda_2^2} \right\}$
 (C) $\lambda = \left\{ \frac{\lambda_1^2 \lambda_2^2}{\lambda_1^2 - \lambda_2^2} \right\}$ (D) $\lambda = \frac{2mc}{h} \left\{ \frac{\lambda_1^2 \lambda_2^2}{\lambda_1^2 - \lambda_2^2} \right\}$

48. In H-atom, if 'x' is the radius of the first Bohr orbit, de Broglie wavelength of an electron in 3rd orbit is:

- (A) $3\pi x$ (B) $6\pi x$ (C) $\frac{9x}{2}$ (D) $\frac{x}{2}$

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

- (A) $\sqrt{\frac{150}{V}} \text{ \AA}$ (B) $\frac{0.286}{\sqrt{V}} \text{ \AA}$ (C) $\frac{0.101}{\sqrt{V}} \text{ \AA}$ (D) $\frac{0.983}{\sqrt{V}} \text{ \AA}$

50. de-Broglie wavelength of electron in second orbit of Li^{2+} ion will be equal to de-Broglie of wavelength of electron in

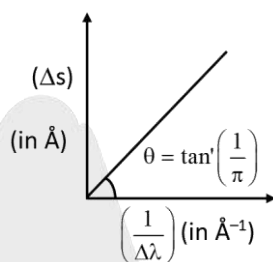
- (A) $n = 3$ of H-atom (B) $n = 4$ of C^{5+} ion
 (C) $n = 6$ of Be^{3+} ion (D) $n = 3$ of He^+ ion

Heisenberg Uncertainty Principle

51. Uncertainty in the position of an electron (mass 9.1×10^{-31} kg) moving with a velocity 300 ms^{-1} , accurate up to 0.001% will be : ($\frac{h}{2m_e} = 5.8 \times 10^{-5}$)

(A) $19.2 \times 10^{-2} \text{ m}$ (B) $5.76 \times 10^{-2} \text{ m}$
(C) $3.84 \times 10^{-2} \text{ m}$ (D) $1.92 \times 10^{-2} \text{ m}$

52. A graph is plotted between uncertainty in position and inverse of uncertainty in wavelength for an electron. We get a straight line passing through origin. Calculate voltage through which electron is accelerated with -



(A) 150 V (B) 75 V (C) 37.5 V (D) 300 V

53. What is uncertainty in location of a photon of wavelength 5000 Å if wavelength is known to an accuracy of 1 pm?

(A) $7.96 \times 10^{-14} \text{ m}$ (B) 0.02 m
(C) $3.9 \times 10^{-8} \text{ m}$ (D) none

54. Assuming Heisenberg Uncertainty Principle to be true what could be the minimum uncertainty in de-Broglie wavelength of a moving electron accelerated by Potential Difference of 6 V whose uncertainty in position is $\frac{7}{22} \text{ n.m.}$

(A) 6.25 Å (B) 6 Å (C) 0.625 Å (D) 0.3125 Å

Schrodinger Equation

55. Which orbital is non-directional

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

56. The quantum number which determines the shape of the orbital is:-

(A) magnetic quantum number. (B) azimuthal quantum number.
(C) principal quantum number. (D) spin quantum number.

57. Orbital with maximum symmetry is:-

(A) p-orbital (B) s-orbital (C) d_{xy} -orbital (D) d_{z^2} -orbital

58. The probability of finding P_y electron is zero in

(A) XY-plane

(B) YZ-plane

(C) XZ-plane

(D) Y-axis

59 The number of nodal planes in $2p_x$ orbital is:-

(A) zero

(B) 1

(C) 2

(D) infinite

60 The orbital having two spherical node is:-

(A) 1s

(B) 2s

(C) 3s

(D) 2p

61 The number of radial nodes of 3s, 3p and 3d electrons are, respectively.

(A) 0, 1, 2

(B) 2, 1, 0

(C) 2, 2, 2

(D) 1, 3, 5

62 Number of nodal surface in 4p orbital is:-

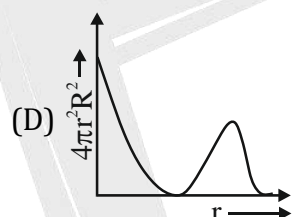
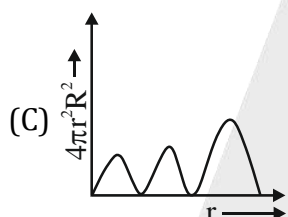
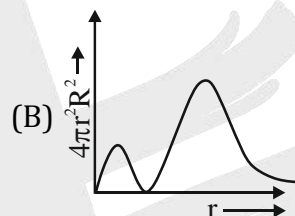
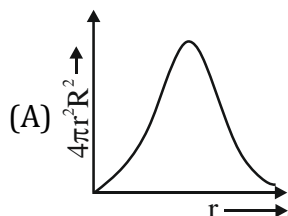
(A) 5

(B) 4

(C) 3

(D) 0

63 Which of the following graph represents the radial probability function of 3d electron?



64 For an electron in a hydrogen atom, the wave function is given by $\Psi_{1s} = (\pi/\sqrt{2})e^{-r/a_0}$, where a_0 is the radius of first Bohr's orbit and r is the distance from the nucleus with which the probability of finding electron varies. What will be the ratio of probabilities of finding electrons at the nucleus to first Bohr's orbit a_0 ?

(A) 0

(B) e

(C) e^2 (D) $\frac{1}{e^2}$

65. 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 :-

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

66. For an electron, with $n = 3$ has only one radial node. The orbital angular momentum of the electron will be

- (A) 0 (B) $\sqrt{6} \frac{h}{2\pi}$ (C) $\sqrt{2} \frac{h}{2\pi}$ (D) $3 \left(\frac{h}{2\pi} \right)$

67. In an atomic orbital, the sign of lobes indicates the :

- (A) sign of the probability distribution
(B) sign of charge
(C) sign of the wave function
(D) presence or absence of electron



EXERCISE # S-I

Rutherford Model

1. The approximate radius of a H-atom is 0.05 nm, and that of proton is 1.5×10^{-15} m. Assuming both the hydrogen atom and the proton to be spherical, calculate fraction of the space in an atom of hydrogen that is occupied by the nucleus.
2. Find the radius of nucleus of an atom having atomic mass number equal to 125.
(Take $R_0 = 1.3 \times 10^{-15}$ m)

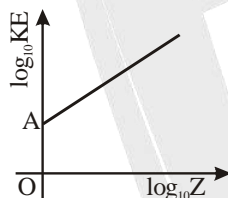
Plancks Quantum theory, No. of Photons

3. Calculate the energy of 100 photons if the wavelength of the light is 2000 Å.
4. How many photons are emitted per second by a 5 mW laser operating at 620 nm?
5. Two bulbs 'A' and 'B' emit red light and yellow light at 8000 Å and 4000 Å respectively. The number of photons emitted by both the bulbs per second is the same. If the red bulb is labelled as 100 watts, find the wattage of the yellow bulb.
6. The eyes of certain member of the reptile family pass a single visual signal to the brain when the visual receptors are struck by photons of wavelength 850 nm. If a total energy of 3.15×10^{-14} J is required to trip the signal, what is the minimum number of photons that must strike the receptor.
7. Find the number of photons of radiation of frequency $5 \times 10^{13} \text{ s}^{-1}$ that must be absorbed in order to melt one gm ice when the latent heat of fusion of ice is 330 J/g.
8. One quantum is absorbed per gaseous molecule of Br_2 for converting into Br atoms. If light absorbed has wavelength 5000 Å, calculate energy required in kJ/mol.
9. A photon having $\lambda = 854 \text{ Å}$ causes the ionization of a nitrogen atom. Give the ionisation energy of nitrogen atom in KJ/mol.
10. A certain dye absorbs 4530 Å and fluoresces at 5080 Å these being wavelengths of maximum absorption that under given conditions 47% of the absorbed energy is emitted. Calculate the ratio of the number of quanta emitted to the number absorbed.
11. The reaction between H_2 and Br_2 to form HBr in presence of light is initiated by the photo decomposition of Br_2 into free Br atoms (free radicals) by absorption of light. The bond dissociation energy of Br_2 is 192 KJ/mole. What is the longest wavelength (in Å) of the photon that would initiate the reaction.

12. The dissociation energy of H_2 is 430.53 kJ/mol. If H_2 is exposed to radiation of wavelength 253.7 nm, what % of radiant energy will be converted into K.E.
13. The quantum yield for decomposition of HI is 0.2. In an experiment 0.01 moles of HI are decomposed. Find the number of photons absorbed.

Bohr's Model

14. If the velocity of the electron in first orbit of H atom is 2.18×10^6 m/s, what is its value in third orbit ?
15. Calculate energy (in J) of electron which is moving in the orbit that has its radius sixteen times the radius of first Bohr orbit for H-atom.
16. The radius of an orbit of hydrogen atom is 0.85 nm. Calculate the velocity (in m/sec) of electron in this orbit.
17. The energy of an excited H-atom is -3.4 eV. Calculate angular momentum of e^- in the given orbit.
18. In a H-like atom for an electron revolving in n th orbit, the variation of $\log_{10} KE$ versus $\log_{10} Z$ is plotted as following –



where Z is atomic number & KE is kinetic energy of electron (in eV). If $OA = \log_{10} 3.4$ then find the value of principle quantum number of the electron.

19. Two bulbs A and B are emitting monochromatic light of wavelength such that A can just ionise H atoms & B can just ionise He^+ ions. If the power of A & B are 30 W & 40 W respectively. Calculate the ratio of number of photons emitted per second by bulb A to bulb B ?
20. A hydrogen sample is prepared in a particular excited state. Photons of energy 2.55 eV get absorbed into the sample to take some of the electrons to a further excited state B. Find orbit numbers of the states A and B. Given the allowed energies of hydrogen atom :
 $E_1 = -13.6$ eV, $E_2 = -3.4$ eV, $E_3 = -1.5$ eV, $E_4 = -0.85$ eV, $E_5 = -0.54$ eV
21. If first ionization potential of a hypothetical atom is 16 V, then the first excitation potential will be :

22. A doubly ionised lithium atom is hydrogen like with atomic number $z = 3$. Find the wavelength (in Å) of the radiation required to excite the electron in Li^{2+} from the first to the third Bohr orbit.
23. Estimate the difference in energy (in eV) between I and II Bohr Orbit for a hydrogen atom. At what minimum atomic number a transition from $n=2$ to $n=1$ energy level would result in the emission of X-rays with $\lambda = 3.0 \times 10^{-8} \text{ m}$? Which hydrogen like species does this atomic number correspond to.
24. Calculate the frequency of e^- in the first Bohr orbit in a H-atom.
25. Find the ratio of the time period of 2nd Bohr orbit of He^+ and 4th Bohr orbit of Li^{2+} .
26. If the average life time of an excited state of H atom is of order 10^{-8} sec , estimate how many orbits an e^- makes when it is in the state $n = 2$ and before it suffers a transition to $n = 1$ state.
27. A hydrogen like atom with atomic number 'Z' is in higher excited state of quantum number 'n'. This excited state atom can make a transition to the first excited state by successively emitting two photons of energies 10 eV and 68.2 eV respectively. Alternatively, the atom from the same excited state can make a transition to the 2nd excited state by emitting two photons of energies 4.25 eV and 5.95 eV respectively. Calculate the value of 'Z'.

Spectrum

28. Find the number of spectral lines in Paschen series emitted by atomic H, when electron is excited from ground state to 7th energy level returns back.
29. Electrons in the H-atoms jump from some higher level to 3rd energy level. If six spectral lines are possible for the transition, find the initial position of electron.
30. What electron transition in the He^+ spectrum would have the same wavelength as the first Lyman transition of hydrogen.
31. Calculate the frequency of light emitted for an electron transition from the sixth to second orbit of the hydrogen atom. In what region of the spectrum does this light occur?
32. Calculate the total energy (J/mole) emitted when electrons of 1.0 g atom of hydrogen undergo transition giving the spectral line of lowest energy in the visible region of its atomic spectrum.
33. Ionization energy of H-atom is 13.6 eV. If H-atom is in the ground state is excited by monochromatic light of energy 12.1 eV then the number of spectral lines emitted when electrons return to ground state

34. H- atom is exposed to electromagnetic radiation of 1026 \AA and gives out induced radiations (radiations emitted when e^- returns to ground state). Calculate λ (in \AA) of induced radiations.
35. Electrons in a sample of H-atoms make transition from state $n = x$ to some lower excited state. If one of the maximum energy photons has an energy of 0.6375 eV , find the value of x . [Take $0.6375 \text{ eV} = \frac{3}{4} \times 0.85 \text{ eV}$]
36. In a container a mixture is prepared by mixing of three samples of hydrogen, helium ion (He^+) and lithium ion (Li^{2+}). In sample all the hydrogen atoms are in 1st excited state and all the He^+ ions are in third excited state and all the Li^{2+} ions are in fifth excited state. Find the total number of spectral lines observed in the emission spectrum of such a sample, when the electrons return back up to the ground state.

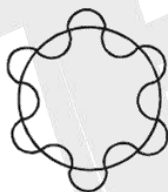
Photoelectric Effect

37. Calculate the threshold frequency (in s^{-1}) of metal if the binding energy is $180.69 \text{ KJ mol}^{-1}$ of electron.
38. The work function for a metal is 40 eV . To emit photo electrons of zero velocity from the surface of the metal the wavelength of incident light should be $x \text{ nm}$.
39. A metal was irradiated by light of frequency $3.2 \times 10^{15} \text{ S}^{-1}$. The photoelectron produced had its KE, 2 times the KE of the photoelectron which was produced when the same metal was irradiated with a light of frequency $2.0 \times 10^{15} \text{ S}^{-1}$. What is work function (in kJ/mole).
40. A stationary He^+ ion emitted a photon corresponding to a first line of the Lyman series. The photon liberated a photoelectron from a stationary H atom in ground state. What is the velocity (in cm/sec.) of photoelectron.
41. The K.E. of an electron emitted from tungsten surface is 3.06 eV . What voltage would be required to bring the electron to rest.

De-Broglie Hypothesis

42. Find the ratio of speed when the De-Broglie wavelength associated with an electron would be equal to that associated with a proton if a proton is 1836 times heavier than an electron.
43. If an electron having kinetic energy 2 eV is accelerated through the potential difference of 2 Volt . Then calculate the wavelength associated with the electron.

44. An electron in a H-atom in its ground state absorbs 1.5 times as much energy as the minimum required for its escape (13.6 eV) from the atom. What is wavelength of the emitted electron.
45. To what effective potential (in volt) a proton beam be subjected to give its protons a wavelength of 1×10^{-10} m.
46. Calculate the de-Broglie wavelength (in m) associated with motion of earth (mass 6×10^{24} Kg) orbiting around the sun at a speed of 3×10^6 m/s.
47. An electron, practically at rest, is initially accelerated through a potential difference of 100 volts. It then has a de Broglie wavelength $= \lambda_1 \text{ \AA}$. It then get retarded through 19 volts and then has a wavelength $\lambda_2 \text{ \AA}$. A further retardation through 32 volts changes the wavelength to $\lambda_3 \text{ \AA}$, What is $\frac{\lambda_3 - \lambda_2}{\lambda_1}$?
48. Photon having energy equivalent to the binding energy of 4th state of He^+ atom is used to eject an electron from the metal surface of work function 1.4 eV. If electrons are further accelerated through the potential difference of 4V then the minimum value of de-Broglie wavelength associated with the electron is :
49. The figure shows a sample of H-atoms having electron revolving in higher orbit 'n'.



If this electron makes transition from this orbit 'n' to ground state, number of Paschen lines emitted are.

50. de-Broglie wavelength associated with an electron in 4th orbit of hydrogen atom is $a \times (\pi r_0)$ where r_0 is radius of 1st orbit of hydrogen atom, find value of 'a'.

Heisenberg Uncertainty Principle

51. A proton is accelerated to one- tenth of the velocity of light. If its velocity can be measured with a precision $\pm 1\%$. What must be its uncertainty in position (in m).
52. If uncertainties in measurement of position and momentum of an electron are equal, then the uncertainty in measurement of its velocity is $x \times 10^{12}$. The value of x (the closest whole number value) is : $m_e = 9.1 \times 10^{-31}$ kg, and $h = 6.625 \times 10^{-34}$ Js.
53. The uncertainty in position and velocity of the particle are 0.1 nm and $5.27 \times 10^{-24} \text{ ms}^{-1}$ respectively then find the mass of the particle. ($h = 6.625 \times 10^{-34}$ Js)

Schrödinger wave equation and orbital concept

54. Find : (a) The number of radial nodes of 5s atomic orbital
(b) The number of angular nodes of $3d_{yz}$ atomic orbital
(c) The sum of angular nodes and radial nodes of $4d_{xy}$ atomic orbital
(d) The number of angular nodes of 3p atomic orbital
55. How many non-spherical orbitals are possible that have at least two maxima if a curve is plotted between radial probability distribution function versus radial distance for which principal quantum number: $n \leq 4$?
56. The ratio of angular nodes of 3d orbital and radial nodes of 3p orbital is $x : 1$ what is the value of x.
57. The radial distribution curve of 2s sublevel consists of x nodes, Find out value of x.
58. Calculate the distance of spherical nodes for '3s' orbital from nucleus?

$$R_{3s} = \frac{1}{9\sqrt{3}a_0^{3/2}} (6 - 6\sigma + \sigma^2) e^{-\frac{\sigma}{2}} \quad \text{where } \sigma = \frac{2r}{na_0}$$

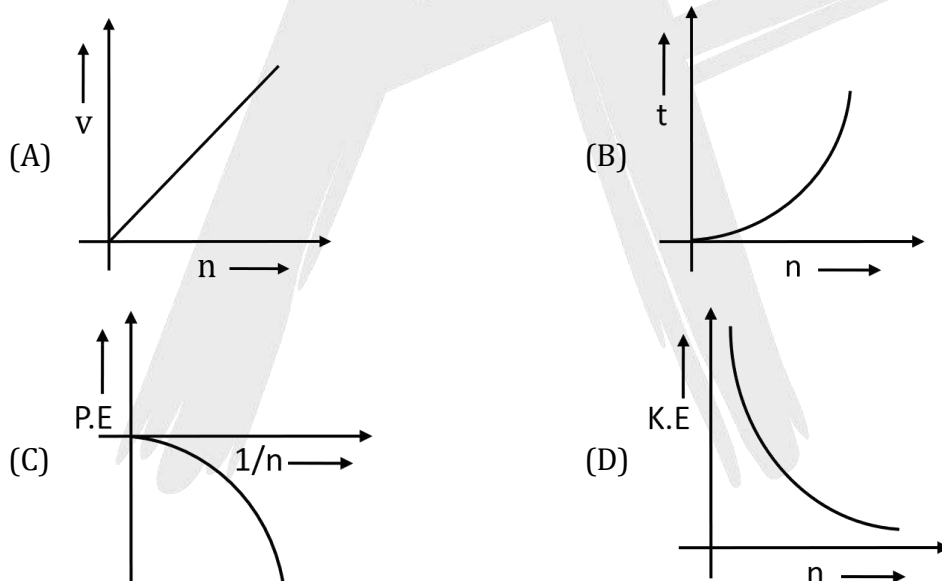
More than one may be correct

- Which of the following could be concluded from Rutherford's α -particle scattering experiment-
 - Most of the space in the atom is empty
 - The radius of the atom is about 10^{-10} m while that of nucleus is 10^{-15} m
 - Electrons move in a circular path of fixed energy called orbits
 - Radius of nucleus is directly proportional to cubic root of mass number.
- Select the incorrect statement(s):
 - All electromagnetic radiation travel with speed of light in vacuum.
 - Energy of photon of UV light is lower than that of yellow light.
 - He^+ and H have same spectrum.
 - The total energy of an electron in uni-electronic specie is greater than zero
- A sodium street light gives off yellow light that has a wavelength of 600 nm. Then
 (For energy of a photon take $E = \frac{12400 \text{ eV } \text{\AA}}{\lambda(\text{\AA})}$)

(A) frequency of this light is $7 \times 10^{14} \text{ s}^{-1}$	(B) frequency of this light is $5 \times 10^{14} \text{ s}^{-1}$
(C) wave number of the light is $3 \times 10^6 \text{ m}^{-1}$	(D) energy of the photon is approximately 2.07 eV
- Choose the incorrect statement(s):
 - Increasing order of wavelength is
Micro waves > Radio waves > IR waves > visible waves > UV waves
 - The order of Bohr radius is (r_n : where n is orbit number for a given atom)
 $r_1 < r_2 < r_3 < r_4$
 - The order of total energy is (E_n : where n is orbit number for a given atom)
 $E_1 > E_2 > E_3 > E_4$
 - The order of velocity of electron in H, He^+ , Li^+ , Be^{3+} species in second Bohr orbit is
 $\text{Be}^{3+} > \text{Li}^{+2} > \text{He}^+ > \text{H}$
- The change in angular momentum corresponding to an electron in Balmer transition inside a hydrogen atom can be :

(A) $\frac{h}{4\pi}$	(B) $\frac{h}{\pi}$	(C) $\frac{h}{2\pi}$	(D) $\frac{h}{8\pi}$
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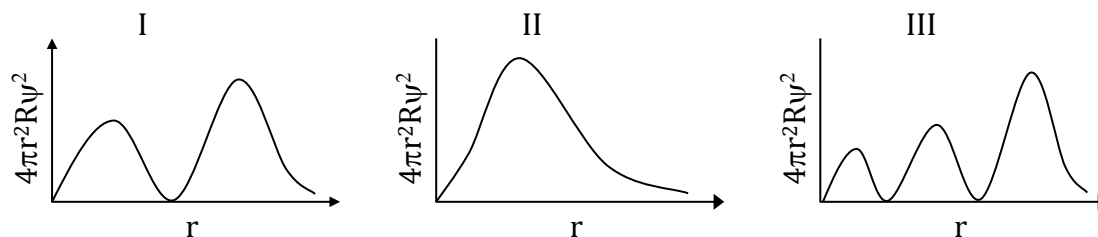
6. 1st excitation potential for the H-like (hypothetical) sample is 24 V. Then :
- (A) Ionisation energy of the sample is 36 eV
 (B) Ionisation energy of the sample is 32 eV
 (C) Binding energy of 3rd excited state is 2 eV
 (D) 2nd excitation potential of the sample is $\frac{32 \times 8}{9}$ V
7. In a H-like sample electrons make transition from 5th excited state to 2nd excited state
- (A) 10 different spectral lines will be emitted
 (B) 6 different spectral lines will be emitted
 (C) Number of lines belonging to Balmer series will be 4
 (D) Number of lines belonging to Paschen series will be 3
8. Select the correct curve(s):
- If v = velocity of electron in Bohr's orbit
 r = Radius of electron in Bohr's orbit
 P.E. = Potential energy of electron in Bohr's orbit
 K.E. = Kinetic energy of electron in Bohr's orbit



9. Which is / are correct statement.
- (A) The difference in angular momentum associated with the electron present in consecutive orbits of H-atom is $(n-1) \frac{h}{2\pi}$
- (B) Energy difference between energy levels will be changed if, P.E. at infinity assigned value other than zero.
- (C) Frequency of spectral line in a H-atom is in the order of $(2 \rightarrow 1) < (3 \rightarrow 1) < (4 \rightarrow 1)$
- (D) On moving away from the nucleus, kinetic energy of electron decreases

10. The kinetic energy of photoelectron emitted on irradiating a metal surface with frequency ν is related by $KE = h\nu - \phi$. The plots of KE vs. incident ν shows :
- (A) A straight line with slope equal to Planck's constant.
 - (B) A straight line with intercept on x-axis equal to the product of threshold frequency and Plank's constant.
 - (C) A straight line with extrapolated intercept on y-axis equal to threshold energy.
 - (D) A straight line with intercept on x-axis equal to threshold frequency
11. Which statements is/are correct regarding the photoelectric effect -
- (A) There is no electron ejection, regardless of intensity of the radiation unless the frequency, exceeds a threshold value which is the characteristics of metals
 - (B) Kinetic energy of ejected electrons varies linearly with the frequency of incident radiation and its photo intensity
 - (C) Even at low intensity, electrons are ejected if the frequency of incident light is more than the threshold frequency
 - (D) An intense and weak beam of same monochromatic radiation differs in having number photons and not in the energy of photons
12. Which of the following is the nodal plane of d_{xy} orbital ?
- (A) XY (B) YZ (C) ZX (D) All
13. Choose the correct statement among the following
- (A) Radial probability distribution function ($\Psi^2 \cdot 4\pi r^2 dr$) gives probability at a particular distance along one chosen direction
 - (B) $\Psi^2(r)$ gives probability density at a particular distance over a spherical surface
 - (C) For 's' orbitals $\Psi(r)\Psi(\theta)\Psi(\phi) = \Psi(x, y, z)$ is independent of θ and ϕ
 - (D) '2p' orbital with quantum numbers. $n = 2, \ell = 1, m = 0$, also shows angular dependence
14. Correct statement(s) regarding $3P_y$ orbital is/are
- (A) Angular part of wave function is independent of angles (θ and ϕ)
 - (B) Number of maxima when a curve is plotted between $4\pi r^2 R^2(r)$ vs r are '2'
 - (C) 'xz' plane acts as nodal plane
 - (D) Magnetic quantum number must be '-1'

15. Which of following has correct matching of curve and orbital



- | | | |
|-----------|--------|---------|
| (A) I(2p) | II(1s) | III(4p) |
| (B) I(3p) | II(3d) | III(3s) |
| (C) I(4d) | II(2p) | III(3d) |
| (D) I(2s) | II(4f) | III(3d) |

Assertion and Reason :

16. It is a data sufficiency problem in which it is to be decided on the basis of given statements whether the given question can be answered or not. No matter whether the answer is yes or number

Question : Is the orbital of hydrogen atom $3p_x$?

Statement-1: The radial function of the orbital is $R(r) = \frac{1}{9\sqrt{6}a_0^{3/2}} (4 - \sigma) \sigma e^{-\sigma/2}$, $\sigma = \frac{r}{2}$

Statement-2: The orbital has 1 radial node & 0 angular node.

- | | |
|--|---------------------------------------|
| (A) Statement (1) alone is sufficient. | (B) Statement (2) alone is sufficient |
| (C) Both together is sufficient. | (D) Neither is sufficient |

17. **Statement-1:** Energy emitted when an electron jump from $5 \rightarrow 2$ (energy level) is less than when an electron jump from $2 \rightarrow 1$ in all 'H' like atom.

Statement-2: The |total energy difference| between 1st & 2nd energy level is greater than that of any two energy level provided level '1' is not part of those two energy levels.

- (A) Statement-1 is true, statement-2 is true and statement-2 is correct explanation for statement-1.
- (B) Statement-1 is true, statement-2 is true and statement-2 is NOT the correct explanation for statement-1.
- (C) Statement-1 is true, statement-2 is false.
- (D) Statement-1 is false, statement-2 is true.

18. Statement-1: Emitted radiations will fall in visible range when an electron jump from higher level to $n = 2$ in Li^{+2} ion.

Statement-2: First four lines of Balmer series of H-atom belong to visible range.

- (A) Statement-1 is true, statement-2 is true and statement-2 is correct explanation for statement-1.
 (B) Statement-1 is true, statement-2 is true and statement-2 is NOT the correct explanation for statement-1.
 (C) Statement-1 is true, statement-2 is false.
 (D) Statement-1 is false, statement-2 is true.

Match the column :

19. Column-I

- (A) Electron moving in 2nd orbit in He^+ ion electron is
 (B) Electron moving in 3rd orbit in H-atom
 (C) Electron moving in 1st orbit in Li^{+2} ion
 (D) Electron moving in 2nd orbit is Be^{+3} ion

Column-II

- (P) Radius of orbit in which moving is 0.529 \AA
 (Q) Total energy of electron is $(-13.6 \times 9 \text{ eV})$
 (R) Velocity of electron is $\frac{2.188 \times 10^6}{3} \text{ m/sec.}$
 (S) de-Broglie wavelength of electron is $\sqrt{\frac{150}{13.6}} \text{ \AA}$

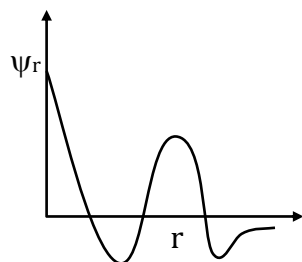
20. Match the following :

- | | |
|---|--|
| (a) Energy of ground state of He^+ | (i) $+ 6.04 \text{ eV}$ |
| (b) Potential energy of I orbit of H-atom | (ii) -27.2 eV |
| (c) Kinetic energy of II excited state of He^+ | (iii) 54.4 V |
| (d) Ionisation potential of He^+ | (iv) $- 54.4 \text{ eV}$ |
| (A) a – (i), b – (ii), c – (iii), d – (iv) | (B) a – (iv), b – (iii), c – (ii), d – (i) |
| (C) a – (iv), b – (ii), c – (i), d – (iii) | (D) a – (ii), b – (iii), c – (i), d – (iv) |

21. Column I & Column II contain data on Schrödinger Wave-Mechanical model, where symbols have their usual meanings. Match the columns.

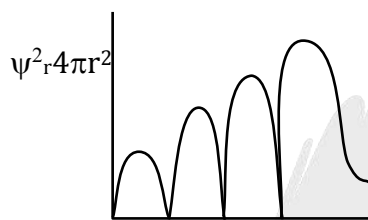
Column I

Column II (Type of orbital)



(A)

(P) 4s



(B)

(Q) 5P_x(C) $\Psi(\theta, \phi) = K$ (independent of θ & ϕ)

(R) 3s

(D) at least one angular node is present

(S) 6d_{xy}

Paragraph Question Number 22 to 24

The French physicist Louis de Broglie in 1924 postulated that matter, like radiation, should exhibit a dual behavior. He proposed the following relationship between the wavelength λ of a material particle, its linear momentum p and Planck constant h .

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

The de Broglie relation implies that the wavelength of a particle should decrease as its velocity increases. It also implies that for a given velocity heavier particles should have shorter wavelength than lighter particles. The waves associated with particles in motion are called matter waves or de Broglie waves. These waves differ from the electromagnetic waves as they

- (i) have lower velocities
- (ii) have no electrical and magnetic fields and
- (iii) are not emitted by the particle under consideration.

The experimental confirmation of the de Broglie relation was obtained when Davisson and Germer, in 1927, observed that a beam of electrons is diffracted by a nickel crystal. As diffraction is a characteristic property of waves, hence the beam of electron behaves as a wave, as proposed by de Broglie.

Werner Heisenberg considered the limits of how precisely we can measure properties of an electron or other microscopic particle like electron. He determined that there is a fundamental

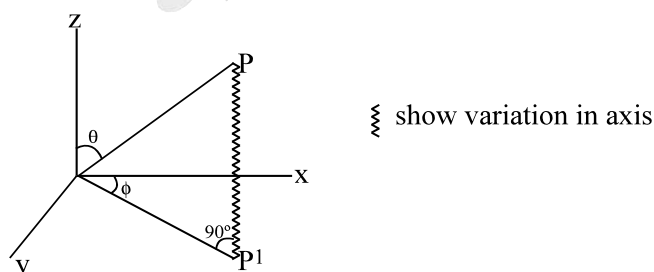
limit of how closely we can measure both position and momentum. The more accurately we measure the momentum of a particle, the less accurately we can determine its position. The converse is also true. This is summed up in what we now call the "Heisenberg uncertainty principle: It is impossible to determine simultaneously and precisely both the momentum and position of a particle. The product of uncertainty in the position, Δx and the uncertainty in the momentum $\Delta(mv)$ must be greater than or equal to $\frac{h}{4\pi}$.i.e.

$$\Delta x \Delta(mv) \geq \frac{h}{4\pi}$$

22. The correct order of wavelength of Hydrogen (${}_1\text{H}^1$), Deuterium (${}_1\text{H}^2$) and Tritium (${}_1\text{H}^3$) moving with same kinetic energy is
 (A) $\lambda_{\text{H}} > \lambda_{\text{D}} > \lambda_{\text{T}}$ (B) $\lambda_{\text{H}} = \lambda_{\text{D}} = \lambda_{\text{T}}$ (C) $\lambda_{\text{H}} < \lambda_{\text{D}} < \lambda_{\text{T}}$ (D) $\lambda_{\text{H}} < \lambda_{\text{D}} > \lambda_{\text{T}}$
23. The transition, so that the de-Broglie wavelength of electron becomes 3 times of its initial value in He^+ ion will be
 (A) $2 \rightarrow 5$ (B) $3 \rightarrow 2$ (C) $2 \rightarrow 6$ (D) $1 \rightarrow 2$
24. If the uncertainty in velocity & position is same, then the uncertainty in momentum will be
 (A) $\sqrt{\frac{4m}{4\pi}}$ (B) $m \sqrt{\frac{h}{4\pi}}$ (C) $\sqrt{\frac{h}{4\pi m}}$ (D) $\frac{1}{m} \sqrt{\frac{h}{4\pi}}$

Paragraph Question Number 25 to 27

After the failure of Bohr atomic theory but its ability to explain the atomic spectra a need was felt for the new model that could incorporate, the concept of stationary orbit, de Broglie concept, Heisenberg uncertainty principle. The concept that incorporate above facts is called quantum mechanics of the atomic model wave mechanical model. It includes set of quantum numbers and $|\psi^2|$ a mathematical expression of the probability of finding an electron at all points in space.



This probability function is the best indication available of how the electron behaves, for as a consequence of the Uncertainty Principle, the amount we can know about the electron is limited. While quantum mechanics can tell us the exact probability of finding an electron at any two particular points, it does not tell us how the electron moves from one of these points to the

other. Thus the idea of an electron orbit is lost; it is replaced with a description of where the electron is most likely to be found. This total picture of the probability of finding an electron at various points in space is called an orbital.

There are various types of orbitals possible, each corresponding to one of the possible combinations of quantum numbers. These orbitals are classified according to the value of n and l associated with them. In order to avoid confusion over the use of two numbers, the numerical values of l are replaced by letters; electrons in orbitals with $l = 0$ are called s-electrons those occupying orbitals for which $l = 1$ are p-electrons and those for which $l = 2$ are called d-electrons. The numerical and alphabetical correspondences are summarized in table. Using the alphabetical notation for l , we would say that in the ground state of hydrogen atom ($n = 1, l = 0$) we have a 1s-electron, or that the electron moves in a 1s-orbital. The relation of the spherical polar co-ordinates r, θ and ϕ to Cartesian coordinates x, y and z . To make the concept of an orbital more meaningful, it is helpful to examine the actual solution of the wave function for the one-electron atom. Because of the spherical symmetry of the atom, the wave functions are most simply expressed in terms of a spherical polar-coordinate system, shown in fig., which has its orbit at the nucleus. It is found that the wave functions can be expressed as the product of two functions, one of which (the "angular part" X) depends only the angle θ and ϕ , the other of which (the "radial part" R) depends only on the distance from the nucleus. Thus we have $\psi(r, \theta, \phi) = R(r) X(\theta, \phi)$

Angular and radial parts of hydrogen atom wave functions

Angular part $X(\theta, \phi)$

$$X(s) = \left(\frac{1}{4\pi}\right)^{1/2}$$

$$X(p_x) = \left(\frac{3}{4\pi}\right)^{1/2} \sin\theta \cos\phi$$

$$X(p_y) = \left(\frac{3}{4\pi}\right)^{1/2} \sin\theta \sin\phi$$

$$X(p_z) = \left(\frac{3}{4\pi}\right)^{1/2} \cos\theta$$

$$X(d_{z^2}) = \left(\frac{5}{16\pi}\right)^{1/2} (3 \cos^2\theta - 1)$$

Radial part $R_{n,l}(r)$

$$R(1s) = 2 \left(\frac{z}{a_0}\right)^{3/2} e^{-\sigma/2}$$

$$R(2s) = \frac{1}{2\sqrt{2}} \left(\frac{z}{a_0}\right)^{3/2} (2 - \sigma) e^{-\sigma/2}$$

$$R(2p) = \frac{1}{2\sqrt{6}} \left(\frac{z}{a_0}\right)^{3/2} \sigma e^{-\sigma/2}$$

$$X(d_{xz}) = \left(\frac{15}{4\pi}\right)^{1/2} \sin\theta \cos\theta \cos\phi$$

$$R(3s) = \frac{1}{9\sqrt{3}} \left(\frac{Z}{a_0}\right)^{3/2} (6 - 6\sigma + \sigma^2)e^{-\sigma/2}$$

$$X(d_{yz}) = \left(\frac{15}{4\pi}\right)^{1/2} \sin\theta \cos\theta \sin\phi$$

$$R(3p) = \frac{1}{9\sqrt{6}} \left(\frac{Z}{a_0}\right)^{3/2} (4 - \sigma)\sigma e^{-\sigma/2}$$

$$X(d_{x^2-y^2}) = \left(\frac{15}{4\pi}\right)^{1/2} \sin^2\theta \cos 2\phi$$

$$R(3d) = \frac{1}{9\sqrt{30}} \left(\frac{Z}{a_0}\right)^{3/2} \sigma^2 e^{-\sigma/2}$$

$$X(d_{xy}) = \left(\frac{15}{4\pi}\right)^{1/2} \sin^2\theta \sin 2\phi$$

$$\sigma = \frac{2Zr}{na_0} ; a_0 = \frac{h^2}{4\pi^2 m e^2}$$

This factorization helps us to visualize the wave function, since it allows us to consider the angular and radial dependences separately. It contains the expression for the angular and radial parts of the one electron atom wave function. Note that the angular part of the wave function for an s-orbital it always the same, $(1/4\pi)^{1/2}$, regardless of principal quantum number. It is also true that the angular dependence of the p-orbitals and of the d-orbitals is independent of principle quantum number. Thus all orbitals of a given types (s, p, or d) have the same angular behaviour. The table shows, however, that the radial part of the wave function depends both on the principal quantum number n and on the angular momentum quantum number l.

To find the wave function for a particular state, we simply multiply the appropriate angular and radial parts together called normalized wave function.

The probability of finding an electron at a point within an atom is proportional to the square of orbital wave function, i.e., ψ^2 at that point. Thus, ψ^2 is known as probability density and always a positive quantity.

$\psi^2 dV$ represents the probability for finding electron in a small volume dV surrounding the nucleus

25. The electron probability density for 1s-orbital is best represented by the relation

$$(A) \frac{1}{2\sqrt{\pi}} \left(\frac{Z}{a_0}\right)^{3/2} \times e^{-\frac{r}{a_0}}$$

$$(B) \frac{1}{\pi} \left(\frac{Z}{a_0}\right)^3 \times e^{-\frac{2Zr}{a_0}}$$

$$(C) \frac{1}{\pi} \left(\frac{Z}{a_0}\right)^3 \times e^{-\frac{2Zr}{a_0}}$$

$$(D) \frac{2}{\pi} \left(\frac{Z}{a_0}\right)^3 e^{-\frac{2Zr}{a_0}}$$

26. If wave functions, $\psi(r, \theta, \phi)$ of 2s and 2p_z electrons in a hydrogen atom are given by

$$\psi(2s) = k_1 \left(2 - \frac{r}{a_0} \right) e^{-r/a_0} \quad \text{and} \quad \psi(2p_z) = k_2 \left(\frac{r}{a_0} \right) e^{-r/a_0} \cos\theta,$$

where $a_0 = 53 \text{ pm}$ and let constants $k_1 = k_2$. If the probability of finding the electron in 2s orbital in a small spherical volume of radius r_0 ($r_0 \ll a_0$) at $r = a_0$ is P_1 and of electron in 2p_z orbital in same spherical volume of radius r_0 ($r_0 \ll a_0$) at $r = a_0$ and $\theta = 30^\circ$ is P_2 then :

- (A) $P_1 > P_2$ (B) $P_1 = P_2$ (C) $P_1 < P_2$ (D) cannot be predicted
27. The angular wave function of which orbital will not disturb by the variation with azimuthal angle
- (A) 1s and 2s (B) 2p_z and 2d_{z²} (C) 2p_x and 3d_{z²} (D) 2p_x and 2s

1. Find the distance of closest approach when an α particle is projected towards the nucleus of silver atom having speed v . (mass of α particle = m_α , atomic number of Ag = 47)
2. An alpha particle after passing through a potential difference of 2×10^6 volt falls on a silver foil. The atomic number of silver is 47. Calculate (i) the K.E. (in Joule) of the alpha-particle at the time of falling on the foil. (ii) K.E. (in Joule) of the α - particle at a distance of 5×10^{-14} m from the nucleus, (iii) the shortest distance (in m) from the nucleus of silver to which the α -particle reaches.
3. A single electron ion has nuclear charge $+Ze$ where Z is atomic number and e is electronic charge. It requires 16.52 eV to excite the electron from the second Bohr orbit to third Bohr orbit. Find
 - (a) The atomic number of element?
 - (b) The kinetic energy (in eV) and potential energy (in eV) of the electron in the first Bohr orbit.
 - (c) The energy required for transition of electron from first to third orbit?
 - (d) Wavelength of photon required to remove electron from first Bohr orbit to infinity?
 - (e) The kinetic energy of electron in first Bohr orbit?
4. The velocity of e^- in a certain Bohr orbit of the hydrogen atom bears the ratio 1:275 to the velocity of light. What is the quantum number " n " of the orbit and the wave number of the radiation emitted for the transition from the quantum state $(n + 1)$ to the ground state.
5. The angular momentum of an electron in a Bohr's orbit of H-atom is 3.1652×10^{-34} kg-m²/sec. Calculate the wave number in terms of Rydberg's constant (R) of the spectral line emitted when an electron falls from this level to the ground state. [Use $h = 6.626 \times 10^{-34}$ Js]
6. A proton captures a free electron whose K.E. is zero & forms a hydrogen atom of lowest energy level ($n = 1$). If a photon is emitted in this process, what will be the wavelength (in Å) of radiation? In which region of electromagnetic spectrum, will this radiation fall? (Ionisation potential of hydrogen = 13.6 volt, $h = 6.6 \times 10^{-34}$ K/s, $C = 3.0 \times 10^8$ m/s)
7. 1.8 g hydrogen atoms are excited to radiations. The study of spectra indicates that 27% of the atoms are in 3rd energy level and 15% of atoms in 2nd energy level and the rest in ground state. If Ionisation energy of H is 21.7×10^{-12} erg. Calculate –
 - (i) Number of atoms present in III & II energy level.
 - (ii) Total energy (in kJ) evolved when all the atoms return to ground state.

8. Electron present in single electron specie jumps from energy level 3 to 1. Emitted photons when passed through a sample containing excited He^+ ion causes further excitation to some higher energy level (Given $E_n = -13.6 \frac{Z^2}{n^2}$). Determine
- Atomic number of single electron specie.
 - principal quantum number of initial excited level & higher energy level of He^+ .
9. The ionisation energy of the hydrogen atom is given to be 13.6 eV. A photon falls on a hydrogen atom which is initially in the ground state and excites it to the ($n = 4$)state. Calculate the wavelength (in Å) of the photon.
10. The ionization energy of a H-like Bohr atom is 4 Rydberg.
- What is the wavelength (in Å) of radiation emitted when the e^- jumps from the first excited state to the ground state.
 - What is the radius (in cm) of first Bohr orbit for this atom. [1 Rydberg = 2.18×10^{-18} J]
11. In the Bohr's model, for uni electronic species following symbols are used
- $r_{n,z}$ → Radius of nth orbit with atomic number "z"
- $U_{n,z}$ → Potential energy of electron in nth orbit with atomic number "z"
- $K_{n,z}$ → Kinetic energy of electron in nth orbit with atomic number "z"
- $v_{n,z}$ → Velocity of electron in nth orbit with atomic number "z"
- $T_{n,z}$ → Time period of revolution of electron in nth orbit with atomic number "z"
- Calculate z in all in cases.
- $U_{1,2} : K_{1,z} = -8 : 1$
 - $r_{1,z} : r_{2,1} = 1 : 8$
 - $v_{1,z} : v_{3,1} = 9 : 1$
 - $T_{1,2} : T_{2,z} = 9 : 32$
12. In a hypothetical H-atom the mass of electron & it charge is double of what we consider then calculate the total energy (in eV) of electron in the 1st orbit of such a hypothetical H-atom ?
- [Assuming all others concepts and parameter to be same as we considered in Bohr's model.]**
13. Photon having wavelength 12.4 nm was allowed to strike a metal plate having work function 25 eV. Calculate the
- Maximum kinetic energy (in eV) of photoelectrons emitted in eV.
 - Wavelength (in Å) of electron with maximum kinetic energy in Å.
 - Calculate the uncertainty in wavelength (in m) of emitted electron if the uncertainty in the momentum is 6.62×10^{-28} Kg m/sec.

14. An electron in Li^{2+} ion makes a transition from higher state n_2 to lower state $n_1 = 6$. The emitted photons are used to ionize an electron in H-atom from 2nd excited state. The electron on leaving the H-atom has a de-Broglie wavelength $\lambda = 12.016 \text{ \AA}$. Find the value of n_2 .

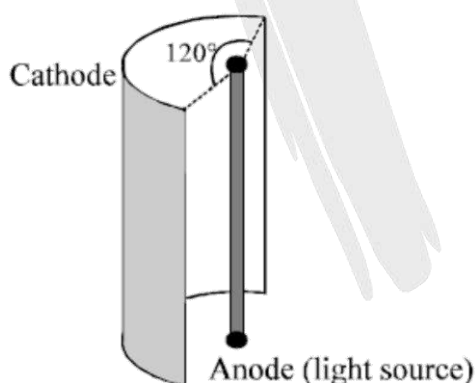
Note : Use $(12.016)^2 = \frac{150 \times 144}{13.6 \times 11}$, $\lambda_{\text{\AA}} = \sqrt{\frac{150}{\text{KE}_{\text{ev}}}}$.

15. The vapours of Hg absorb some electrons accelerated by a potential diff. of 4.5 volt as a result of which light is emitted. If the full energy of single incident e^- is supposed to be converted into light emitted by single Hg atom, find the wave number (in m^{-1}) of the light.
16. A potential difference of 20 KV is applied across an X-ray tube. Find the minimum wavelength (in \AA) of X-ray generated.
17. Suppose the potential energy between electron and proton at a distance r is given by $-\frac{ke^2}{3r^3}$.

Bohr's theory to obtain energy of such a hypothetical atom.

18. A cylindrical source of light which emits radiation radially (from curved surface) only, placed at the centre of a hollow, metallic cylindrical surface, as shown in diagram.

The power of source is 90 watt and it emits light of wavelength 4000 \AA only. The emitted photons strike the metallic cylindrical surface which results in ejection of photoelectrons. All ejected photoelectrons reaches to anode (light source). The magnitude of photocurrent (in amp) is [Given : $h = 6.4 \times 10^{-34} \text{ J/sec.}$]



19. He atom can be excited to $1s^1 2p^1$ by $\lambda = 58.44 \text{ nm}$. If lowest excited state for He lies 4857 cm^{-1} below the above. Calculate the energy for the lower excitation state.
20. Mr. Santa has to decode a number "ABCDEF" where each alphabet is represented by a single digit. Suppose an orbital whose radial wave function is represented as

$$\Psi(r) = k_2 \cdot e^{-r/k_2} (r^2 - 5k_3 r + 2 \cdot 6k_2^3)$$

From the following information given about each alphabet then write down the answers in the form of "ABCDEF", for above orbital.

Info A = Value of n where " n " is principal quantum number

Info B = Number of angular nodes

Info C = Azimuthal quantum number of subshell to orbital belongs

Info D = Number of subshells having energy between $(n + 5)s$ to $(n + 5)p$ where n is principal quantum number

Info E = Orbital angular momentum of given orbital.

Info F = Radial distance of the spherical node which is farthest from the nucleus

(Assuming $k_3 = 1$)



- An atom has a mass of 0.02 kg and uncertainty in its velocity is 9.218×10^{-6} m/s then uncertainty in position is ($h = 6.626 \times 10^{-34}$ Js) [AIEEE 2002]
 (A) 2.86×10^{-28} m (B) 2.86×10^{-32} cm (C) 1.5×10^{-27} m (D) 3.9×10^{-10} m
- Energy of H- atom in the ground state is -13.6 eV, Hence energy in the second excited state is- [AIEEE 2002]
 (A) -6.8 eV (B) -3.4 eV (C) -1.51 eV (D) -4.3 eV
- Uncertainty in position of a particle of 25 g in space is 10^{-5} m. Hence uncertainty in velocity (ms^{-1}) is (Planck's constant $h = 6.6 \times 10^{-34}$ Js) [AIEEE-2002]
 (A) 2.1×10^{-28} (B) 2.1×10^{-34} (C) 0.5×10^{-34} (D) 5.0×10^{-24}
- The orbital angular momentum for an electron revolving in an orbit is given by $\sqrt{\ell(\ell+1)} \cdot \frac{h}{2\pi}$. This momentum for an s-electron will be given by [AIEEE-2003]
 (A) $\sqrt{2} \cdot \frac{h}{2\pi}$ (B) $+\frac{1}{2} \cdot \frac{2}{2\pi}$ (C) zero (D) $\frac{h}{2\pi}$
- The number of d-electrons retained in Fe^{2+} (At. number of Fe = 26) ion is : [AIEEE-2003]
 (A) 6 (B) 3 (C) 4 (D) 5
- The de Broglie wavelength of a tennis ball of mass 60 g moving with a velocity of 10 meters per second is approximately : [AIEEE 2003]
 (A) 10^{-25} meters (B) 10^{-33} meters (C) 10^{-31} meters (D) 10^{-16} meters
- In Balmer series of lines of hydrogen spectrum, the third line from the red end corresponds to which one of the following inter-orbit jumps of the electron for Bohr orbits in an atom of hydrogen ? [AIEEE-2003]
 (A) $2 \rightarrow 5$ (B) $3 \rightarrow 2$ (C) $5 \rightarrow 2$ (D) $4 \rightarrow 1$
- Which of the following sets of quantum number is correct for an electron in 4f orbital ? [AIEEE-2004]
 (A) $n = 3, l = 2, m = -2, s = +\frac{1}{2}$ (B) $n = 4, l = 4, m = -4, s = -\frac{1}{2}$
 (C) $n = 4, l = 3, m = +1, s = +\frac{1}{2}$ (D) $n = 4, l = 3, m = +4, s = +\frac{1}{2}$
- The wavelength of the radiation emitted, when in a hydrogen atom electron falls from infinity to stationary state 1, would be (Rydberg constant = $1.097 \times 10^7 \text{ m}^{-1}$) : [AIEEE-2004]
 (A) 9.1×10^{-8} nm (B) 192 nm (C) 406 nm (D) 91 nm

10. Which of the following statements in relation to the hydrogen atom is correct ? [AIEEE-2005]
(A) 3s, 3p and 3d orbitals all have the same energy
(B) 3s and 3p orbitals are of lower energy than 3d orbitals
(C) 3p orbital is lower in energy than 3d orbital
(D) 3s orbitals is lower in energy than 3p orbital
11. According to Bohr's theory angular momentum of electron in 5th shell is : [AIEEE-2006]
(A) $1.0 h/\pi$ (B) $10 h/\pi$ (C) $2.5 h/\pi$ (D) $25 h/\pi$
12. Uncertainty in the position of an electron (mass = 9.1×10^{-31} Kg) moving with a velocity 300 ms^{-1} , accurate upto 0.001%, will be :- ($h = 6.63 \times 10^{-34}$ Js) [AIEEE-2006]
(A) $5.76 \times 10^{-2} \text{ m}$ (B) $1.92 \times 10^{-2} \text{ m}$ (C) $3.84 \times 10^{-2} \text{ m}$ (D) $19.2 \times 10^{-2} \text{ m}$
13. The ionization enthalpy of hydrogen atom is $1.312 \times 10^6 \text{ J mol}^{-1}$. The energy required to excite the electron in the atom from $n = 1$ to $n = 2$ is [AIEEE-2008]
(A) $8.51 \times 10^5 \text{ J mol}^{-1}$ (B) $6.56 \times 10^5 \text{ J mol}^{-1}$
(C) $7.56 \times 10^5 \text{ J mol}^{-1}$ (D) $9.84 \times 10^5 \text{ J mol}^{-1}$
14. In an atom, an electron is moving with a speed of 600 m/s with an accuracy of 0.005%. Certainty with which the position of the electron can be located is ($h = 6.6 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}$, mass of electron, $m_e = 9.1 \times 10^{-31} \text{ kg}$): [AIEEE-2009]
(A) $1.92 \times 10^{-3} \text{ m}$ (B) $3.84 \times 10^{-3} \text{ m}$ (C) $1.52 \times 10^{-4} \text{ m}$ (D) $5.10 \times 10^{-3} \text{ m}$
15. Calculate the wavelength (in nanometer) associated with a proton moving at $1.0 \times 10^3 \text{ ms}^{-1}$ (Mass of proton = $1.67 \times 10^{-27} \text{ kg}$ and $h = 6.63 \times 10^{-34} \text{ Js}$) : [AIEEE-2009]
(A) 2.5 nm (B) 14.0 nm (C) 0.032 nm (D) 0.40 nm
16. The energy required to break one mole of Cl-Cl bonds in Cl_2 is 242 kJ mol^{-1} . The longest wavelength of light capable of breaking a single Cl-Cl bond is [AIEEE-2010]
($C = 3 \times 10^8 \text{ ms}^{-1}$ and $N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$)
(A) 494 nm (B) 594 nm (C) 640 nm (D) 700 nm
17. Ionisation energy of He^+ is $19.6 \times 10^{-18} \text{ J atom}^{-1}$. The energy of the first stationary state ($n = 1$) of Li^{2+} is: [AIEEE-2010]
(A) $8.82 \times 10^{-17} \text{ J atom}^{-1}$ (B) $4.41 \times 10^{-16} \text{ J atom}^{-1}$
(C) $-4.41 \times 10^{-17} \text{ J atom}^{-1}$ (D) $-2.2 \times 10^{-15} \text{ J atom}^{-1}$
18. A gas absorbs a photon of 355 nm and emits at two wavelengths. If one of the emissions is at 680 nm, the other is at : [AIEEE-2011]
(A) 743 nm (B) 518 nm (C) 1035 nm (D) 325 nm

19. The frequency of light emitted for the transition $n = 4$ to $n = 2$ of He^+ is equal to the transition in H atom corresponding to which of the following [AIEEE-2011]

(A) $n = 3$ to $n = 1$ (B) $n = 2$ to $n = 1$ (C) $n = 3$ to $n = 2$ (D) $n = 4$ to $n = 3$

20. The electrons identified by quantum numbers n and l : [AIEEE-2012]

(a) $n = 4, l = 1$ (b) $n = 4, l = 0$ (c) $n = 3, l = 2$ (d) $n = 3, l = 1$

Can be placed in order of increasing energy as

(A) (a) < (c) < (b) < (d) (B) (c) < (d) < (b) < (a)

(C) (d) < (b) < (c) < (a) (D) (b) < (d) < (a) < (c)

21. 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]

(A) Two times (B) Half (C) One fourth (D) Four times

22. 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]

(A) $6\pi a_0$ (B) $8\pi a_0$ (C) $2\pi a_0$ (D) $4\pi a_0$

23. The wave number of the first emission line in the Balmer series of H-Spectrum is : (R = Rydberg constant) :

(A) $\frac{3}{4} R$ (B) $\frac{9}{400} R$ (C) $\frac{5}{36} R$ (D) $\frac{7}{6} R$

24. The de Broglie wavelength of a car of mass 1000 kg and velocity 36 km/hr is :

($h = 6.63 \times 10^{-34} \text{ Js}$)

[JEE-Main(online) 2013]

(A) $6.626 \times 10^{-31} \text{ m}$ (B) $6.626 \times 10^{-34} \text{ m}$ (C) $6.626 \times 10^{-38} \text{ m}$ (D) $6.626 \times 10^{-30} \text{ m}$

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

(A) a dust particle (B) an electron (C) a proton (D) an α -particle

26. 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]

(A) 13.6 eV (B) 30.6 eV (C) 122.4 eV (D) 3.4 eV

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

$$\Delta E = -2.0 \times 10^{-18} \text{ J} \left(\frac{1}{n_2^2} - \frac{1}{n_1^2} \right)$$

the wavelength of the light that must be absorbed to excite hydrogen electron from level $n = 1$ to level $n = 2$ will be ($h = 6.625 \times 10^{-34} \text{ Js}$, $c = 3 \times 10^8 \text{ ms}^{-1}$)

(A) $2.650 \times 10^{-7} \text{ m}$ (B) $1.325 \times 10^{-7} \text{ m}$ (C) $1.325 \times 10^{-10} \text{ m}$ (D) $5.300 \times 10^{-10} \text{ m}$

28. 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]
- (A) $\sqrt{\frac{2hc}{m} \left(\frac{\lambda_0 - \lambda}{\lambda \lambda_0} \right)}$ (B) $\sqrt{\frac{2h}{m} \left(\frac{1}{\lambda_0} - \frac{1}{\lambda} \right)}$ (C) $\sqrt{\frac{2h}{m} (\lambda_0 - \lambda)}$ (D) $\sqrt{\frac{2hc}{m} (\lambda_0 - \lambda)}$
29. Ionization energy of gaseous Na atoms is $495.5 \text{ kJ mol}^{-1}$. The lowest possible frequency of light that ionizes a sodium atom is
 ($h = 6.626 \times 10^{-34} \text{ Js}$, $N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$) [JEE-Main(online) 2014]
- (A) $3.15 \times 10^{15} \text{ s}^{-1}$ (B) $4.76 \times 10^{14} \text{ s}^{-1}$ (C) $1.24 \times 10^{15} \text{ s}^{-1}$ (D) $7.50 \times 10^4 \text{ s}^{-1}$
30. Which of the following is the energy of a possible excited state of hydrogen? [JEE-Main(offline) 2015]
- (A) -3.4 eV (B) $+6.8 \text{ eV}$ (C) $+13.6 \text{ eV}$ (D) -6.8 eV
31. At temperature T , the average kinetic energy of any particle is kT . The de Broglie wavelength follows the order : [JEE-Main(online) 2015]
- (A) Visible photon > Thermal electron > Thermal neutron
 (B) Thermal proton > Thermal electron > Visible photon
 (C) Visible photon > Thermal neutron > Thermal electron
 (D) Thermal proton > Visible photon > Thermal electron
32. The radius of the second Bohr orbit for hydrogen atom is : [JEE Main 2017]
- (Planck's const. $h = 6.6262 \times 10^{-34} \text{ Js}$
 mass of electron $= 9.1091 \times 10^{-31} \text{ kg}$
 charge of electron $e = 1.60210 \times 10^{-19} \text{ C}$
 permittivity of vacuum $\epsilon_0 = 8.854185 \times 10^{-12} \text{ kg}^{-1} \text{ m}^{-3} \text{ A}^2 \text{ s}^4$)
- (A) 1.65 \AA (B) 4.76 \AA (C) 0.529 \AA (D) 2.12 \AA
33. For emission line of atomic hydrogen from $n_i = 8$ to $n_f =$ the plot of wave number $\left(\bar{\nu} \right)$ against $\left(\frac{1}{n^2} \right)$ will be (The Rydberg constant, R_H is in wave number unit). [JEE Main (Jan.) 2019]
- (A) Linear- with slope - R_H (B) Linear with intercept - R_H
 (C) Non linear (D) Linear with slope R_H
34. Which of the following combination of statements is true regarding the interpretation of the atomic orbitals ? [JEE Main (Jan.) 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.

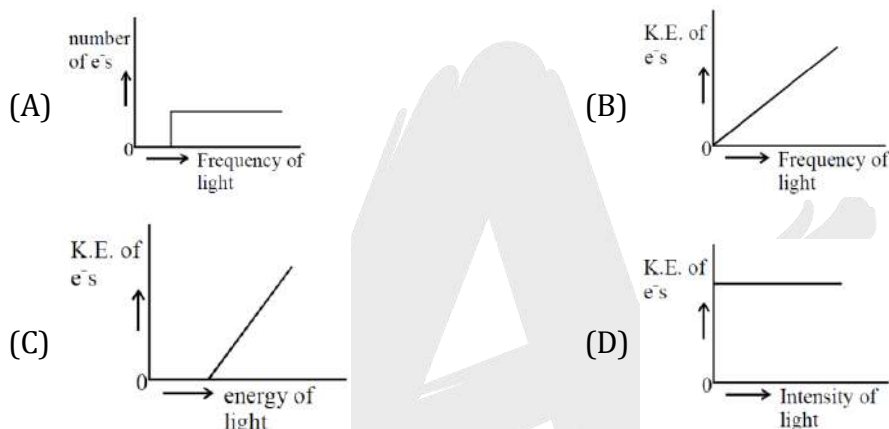
(b) For a given value of the principal quantum number, the size of the orbit is inversely proportional to the azimuthal quantum number.

(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.

(A) (a), (c) (B) (a), (d) (C) (b), (c) (D) (a), (b)

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



36. The ground state energy of hydrogen atom is -13.6 eV. The energy of second excited state He^+ ion in eV is : **[JEE Main (Jan.) 2019]**

(A) -54.4 (B) -6.04 (C) -3.4 (D) -27.2

37. 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 (Jan.) 2019]**

$[R_H = 1 \times 10^5 \text{ cm}^{-1}, h = 6.6 \times 10^{-34} \text{ Js}, c = 3 \times 10^8 \text{ ms}^{-1}]$

(A) Paschen, $5 \rightarrow 3$ (B) Balmer, $\infty \rightarrow 2$ (C) Lyman, $\infty \rightarrow 1$ (D) Paschen, $\infty \rightarrow 3$

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

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

39. What is the work function of the metal if the light of wavelength 4000 \AA generates photoelectrons of velocity $6 \times 10^5 \text{ ms}^{-1}$ from it ?

(Mass of electron = $9 \times 10^{-31} \text{ kg}$)

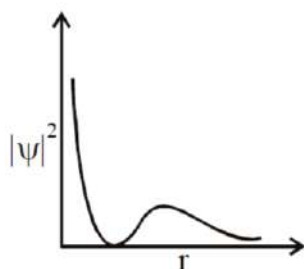
Velocity of light = $3 \times 10^8 \text{ ms}^{-1}$

Planck's constant = $6.626 \times 10^{-34} \text{ Js}$

Charge of electron = $1.6 \times 10^{-19} \text{ J eV}^{-1}$

[JEE Main (Jan.) 2019]

- (A) 2.1 eV (B) 3.1 eV (C) 0.9 eV (D) 4.0 eV
40. 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 (Jan.) 2019]**
- (A) 0.40 (B) 0.75 (C) 1.0 (D) 1.50
41. The quantum number of four electrons are given below : **[JEE Main (April) 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. $n = 3, l = 1, m_l = 1, m_s = -\frac{1}{2}$
- (A) I < III < II < IV (B) IV < III < II < I (C) I < II < III < I (D) IV < II < III < I
42. 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 : (Assume kinetic energy of ejected photoelectron to be very high in comparison to work function) : **[JEE Main (April) 2019]**
- (A) $\frac{3}{4} \lambda$ (B) $\frac{4}{9} \lambda$ (C) $\frac{1}{2} \lambda$ (D) $\frac{2}{3} \lambda$
43. 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 $\Delta \bar{\nu}_{\text{Lyman}} / \Delta \bar{\nu}_{\text{Balmer}}$ is: **[JEE Main (April) 2019]**
- (A) 4 : 1 (B) 5 : 4 (C) 9 : 4 (D) 27 : 4
44. Which one of the following about an electron occupying the 1s orbital in a hydrogen atom is incorrect ? (The Bohr radius is represented by a_0) **[JEE Main (April) 2019]**
- (A) The electron can be found at a distance $2a_0$ from the nucleus
- (B) The total energy of the electron is maximum when it is at a distance a_0 from the nucleus.
- (C) The magnitude of potential energy is double that of its kinetic energy on an average.
- (D) The probability density of finding the electron is maximum at the nucleus.
45. The graph between $|\psi|^2$ and r (radial distance) is shown below. This represents: **[JEE Main (April) 2019]**

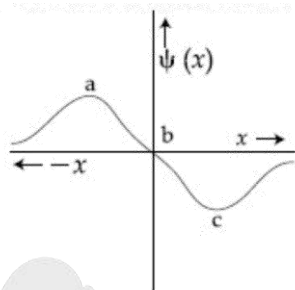


- (A) 1s orbital (B) 3s orbital (C) 2s orbital (D) 2p orbital

46. The ratio of the shortest wavelength of two special series of hydrogen spectrum is found to be about 9. The spectral series are : [JEE Main (April) 2019]

(A) Paschen and Pfund (B) Balmer and Brackett
(C) Lyman and Paschen (D) Brackett and Pfund

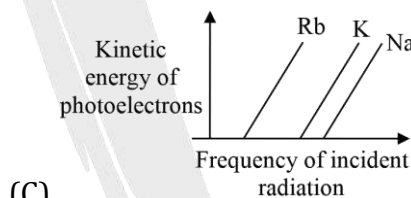
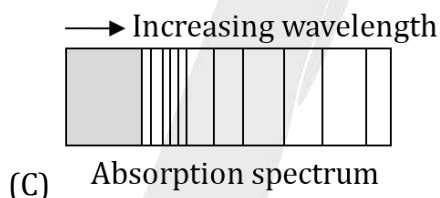
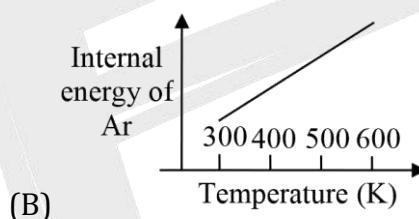
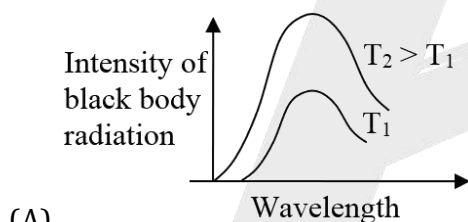
47. The electrons are more likely to be found: [JEE Main (April) 2019]



(A) only in the region c (B) in the region a and c
(C) only in the region a (D) in the region a and b

48. The figure that is not a direct manifestation of the quantum nature of atoms is :

[Jee Main, 2020]



49. The radius of the second Bohr orbit, in terms of the Bohr radius, a_0 , in Li^{2+} is :

[Jee Main, 2020]

(A) $\frac{2a_0}{3}$ (B) $\frac{4a_0}{3}$ (C) $\frac{2a_0}{9}$ (D) $\frac{4a_0}{9}$

50. For the Balmer series in the spectrum of H atom, $\bar{\nu} = R_H \left\{ \frac{1}{n_1^2} - \frac{1}{n_2^2} \right\}$, the correct statements

among (I) to (IV) are :

[Jee Main, 2020]

- (I) As wavelength decreases, the lines in the series converge
(II) The integer n_1 is equal to 2
(III) The lines of longest wavelength corresponds to $n_2 = 3$
(IV) The ionization energy of hydrogen can be calculated from wave number of these lines

(Physical Chemistry)

ATOMIC STRUCTURE

- (A) (I), (III), (IV) (B) (I), (II), (III) (C) (II), (III), (IV) (D) (I), (II), (IV)

51. The work function of sodium metal is 4.41×10^{-19} J. If photons of wavelength 300 nm are incident on the metal, the kinetic energy of the ejected electrons will be ($h = 6.63 \times 10^{-34}$ J s; $c = 3 \times 10^8$ m/s) _____ $\times 10^{-21}$ J. **[Jee Main, 2020]**

52. The correct statement about probability density (except at infinite distance from nucleus) is : **[Jee Main, 2020]**

- (A) It can negative for 2p orbital (B) It can be zero for 1s orbital
(C) It can never be zero for 2s orbital (D) It can be zero for 3p orbital

53. If the Thompson model of the atom was correct, then the result of Rutherford's gold foil experiment would have been : **[JEE Main, July 2021]**

- (A) All of the α -particles pass through the gold foil without decrease in speed.
(B) α -Particles are deflected over a wide range of angles.
(C) All α -particles get bounced back by 180°
(D) α -Particles pass through the gold foil deflected by small angles and with reduced speed.

54. A 50 watt bulb emits monochromatic red light of wavelength of 795 nm. The number of photons emitted per second by the bulb is $x \times 10^{20}$. The value of x is _____.
[Given : $h = 6.63 \times 10^{-34}$ Js and $c = 3.0 \times 10^8$ ms $^{-1}$] **[JEE Main, August 2021]**

55. According to Bohr's atomic theory :- **[JEE Main, Feb 2021]**

- (A) Kinetic energy of electron is $\propto \frac{Z^2}{n^2}$
(B) The product of velocity (v) of electron and principal quantum number (n), ' vn ' $\propto Z^2$
(C) Frequency of revolution of electron in an orbit is $\propto \frac{Z^3}{n^3}$
(D) Coulombic force of attraction on the electron is $\propto \frac{Z^3}{n^4}$

Choose the most appropriate answer from the options given below :

- (A) (C) Only
(B) (A) Only
(C) (A), (C) and (D) only
(D) (A) and (D) only

56. What is the spin-only magnetic moment value (BM) of a divalent metal ion with atomic number 25, in its aqueous solution? [JEE Main, March 2021]

- (A) 5.92 (B) 5.0 (C) zero (D) 5.26

57. The Azimuthal quantum number for the valence electrons of Ga^+ ion is _____. (Atomic number of Ga = 31)

[JEE Main, July 2021]

58. The wavelength of an electron and a neutron will become equal when the velocity of the electron is x times the velocity of neutron. The value of x is _____. (Nearest Integer)
(Mass of electron is 9.1×10^{-31} kg and mass of neutron is 1.6×10^{-27} kg)

[JEE Main, July 2022]

59. The minimum uncertainty in the speed of an electron in a one dimensional region of length $2a_0$ (Where a_0 = Bohr radius 52.9 pm) is _____ km s^{-1} .
(Given: Mass of electron = 9.1×10^{-31} kg, Planck's constant $h = 6.63 \times 10^{-34}$ Js)

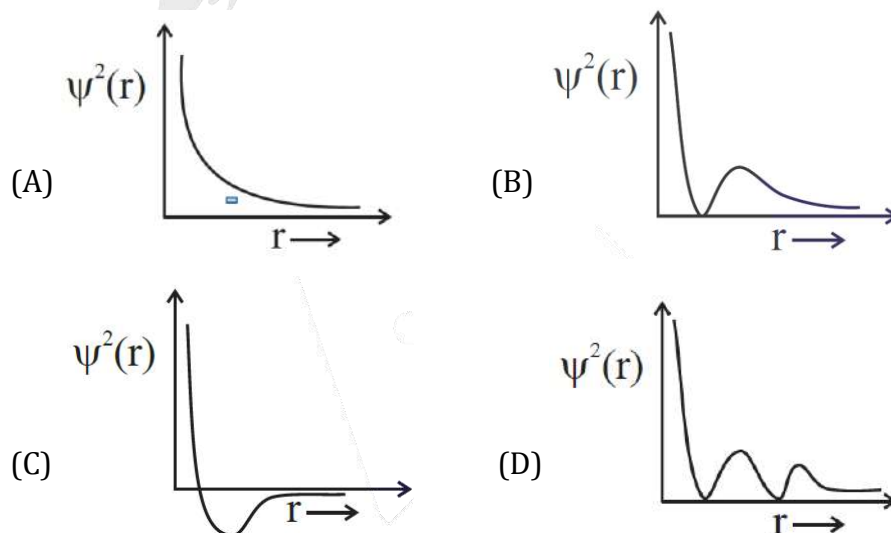
[JEE Main, July 2022]

60. Identify the incorrect statement from the following.

- (A) A circular path around the nucleus in which an electron moves is proposed as Bohr's orbit.
(B) An orbital is the one electron wave function (Ψ) in an atom.
(C) The existence of Bohr's orbits is supported by hydrogen spectrum.
(D) Atomic orbital is characterized by the quantum numbers n and l only

[JEE Main, July 2022]

61. Which of the following is the correct plot for the probability density $\psi^2(r)$ as a function of distance ' r ' of the electron from the nucleus for 2s orbital? [JEE Main, June 2022]



62. Consider the following statements:

[JEE Main, June 2022]

- (A) The principal quantum number 'n' is a positive integer with values of 'n' = 1, 2, 3, ...
(B) The azimuthal quantum number 'l' for a given 'n' (principal quantum number) can have values as 'l' = 0, 1, 2, ..., n
(C) Magnetic orbital quantum number 'm' for a particular 'l' (azimuthal quantum number) has (2l + 1) values.
(D) $\pm 1/2$ are the two possible orientations of electron spin.
(E) For l = 5, there will be a total of 9 orbital.

Which of the above statements are correct?

- (A) (A), (B) and (C)
(B) (A), (C), (D) and (E)
(C) (A), (C) and (D)
(D) (A), (B), (C) and (D)

63. Consider the following pairs of electrons

[JEE Main, June 2022]

- (A) (a) $n = 3, l = 1, m_l = 1, m_s = +\frac{1}{2}$
(b) $n = 3, l = 2, m_l = 1, m_s = +\frac{1}{2}$
(B) (a) $n = 3, l = 2, m_l = -2, m_s = -\frac{1}{2}$
(b) $n = 3, l = 2, m_l = -1, m_s = -\frac{1}{2}$
(C) (a) $n = 4, l = 2, m_l = 2, m_s = +\frac{1}{2}$
(b) $n = 3, l = 2, m_l = 2, m_s = +\frac{1}{2}$

The pairs of electron present in degenerate orbitals is/are:

- (A) Only A (B) Only B (C) Only C (D) (B) and (C)

EXERCISE # (JEE-ADVANCED)

1. The quantum numbers $+1/2$ and $-1/2$ for the electron spin represent: [JEE 2001]
 (A) rotation of the electron in clockwise and anticlockwise direction respectively.
 (B) rotation of the electron in anticlockwise and clockwise direction respectively.
 (C) magnetic moment of the electron pointing up and down respectively.
 (D) two quantum mechanical spin states which have no classical analogue
2. Rutherford's experiment, which established the nuclear model of atom, used a beam of :- [JEE 2002]
 (A) β - particles, which impinged on a metal foil and get absorbed.
 (B) γ - rays, which impinged on a metal foil and ejected electron.
 (C) Helium atoms, which impinged on a metal foil and got scattered.
 (D) Helium nuclei, which impinged on a metal foil and got scattered.
3. The magnetic moment of cobalt of the compound $\text{Hg}[\text{Co}(\text{SCN})_4]$ is [Given : Co^{+2}] [JEE 2004]
 (A) $\sqrt{3}$ (B) $\sqrt{8}$ (C) $\sqrt{15}$ (D) $\sqrt{24}$
4. The radius of which of the following orbit is same as that of the first Bohr's orbit of hydrogen atom? [JEE 2004]
 (A) He^+ ($n = 2$) (B) Li^{2+} ($n = 2$) (C) Li^{2+} ($n = 3$) (D) Be^{3+} ($n = 2$)
5. (a) The Schrodinger wave equation for hydrogen atom is [IIT-2004]

$$\psi_{2s} = \frac{1}{4(2\pi)^{1/2}} \left(\frac{1}{a_0} \right)^{3/2} \left(2 - \frac{r_0}{a_0} \right) e^{-r/a}$$

 Where a_0 is Bohr's radius. Let the radial node in 2s be at r_0 . Then find r_0 in terms of a_0 .
 (b) A base ball having mass 100 g moves with velocity 100 m/s. find out the value of wavelength of base ball.
6. (a) Calculate velocity of electron in first Bohr orbit of hydrogen atom (Given $r = a_0$)
 (b) Find de-Broglie wavelength of the electron in first Bohr orbit. [IIT-2005]
 (c) Find the orbital angular momentum of 2p-orbital in terms of $h/2\pi$ units.
7. Given in hydrogenic atom r_n , V_n , E , K_n stand for radius, potential energy, total energy and kinetic energy in n^{th} orbit. Find the value of U,v,x,y. [JEE 2006]
 (A) $U = \frac{V_n}{K_n}$ (P) 1
 (B) $\frac{1}{r_n} \propto E^x$ (Q) -2
 (C) $r_n \propto Z^y$ (R) -1
 (Z = Atomic number)

- (D) $v =$ (Orbital angular momentum of electron in its lowest energy) (S) 0

8. Match the entries in Column I with the correctly related quantum number(s) in Column II. Indicate your answer by darkening the appropriate bubbles of the 4×4 matrix given in the ORS. [JEE 2008]

Column I

Column II

- | | |
|--|--|
| (A) Orbital angular momentum of the electron in a hydrogen-like atomic orbital | (P) Principal quantum number |
| (B) A hydrogen-like one-electron wave function obeying Pauli principle | (Q) Azimuthal quantum number |
| (C) Shape, size and orientation of hydrogen like atomic orbitals | (R) Magnetic quantum number |
| (D) Probability density of electron at the nucleus | (S) Electron spin quantum number in hydrogen-like atom |

Paragraph for questions 9 to 11

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]

9. The state S_1 is :-
 (A) 1s (B) 2s (C) 2p (D) 3s
10. 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
11. The orbital angular momentum quantum number of the state S_2 is :-
 (A) 0 (B) 1 (C) 2 (D) 3
12. The maximum number of electrons that can have principal quantum number, $n=3$, and spin quantum number, $m_s = -1/2$, is [JEE 2011]
13. 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
$\phi(\text{eV})$	2.4	2.3	2.2	3.7	4.8	4.3	4.7	6.3	4.75

14. 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) $\frac{h^2}{64\pi^2 m a_0^2}$

15. 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°C is "M" times that of the de Broglie wavelength of Ne at 727°C . M is.

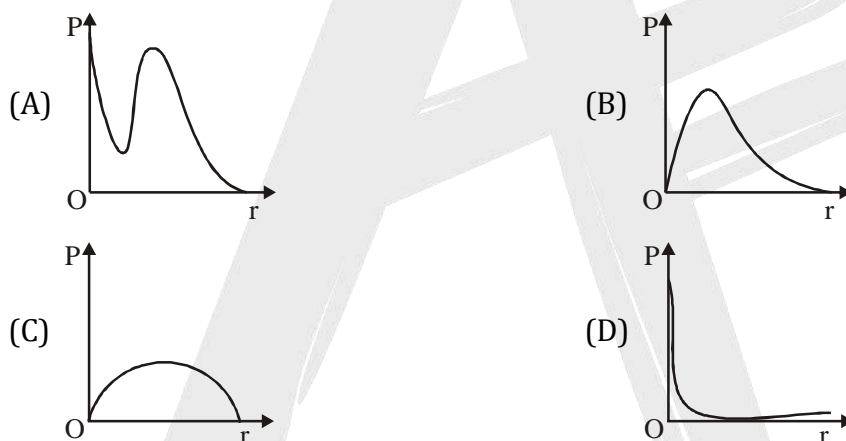
[JEE 2013]

16. 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]

17. 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 -

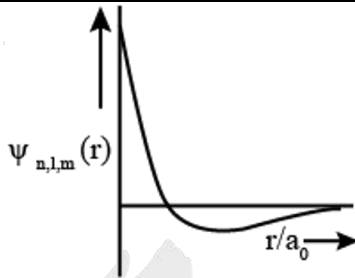
[JEE 2016]



Paragraph for questions 18 to 20

The wave function, Ψ_{n,l,m_l} is a mathematical function whose value depends upon spherical polar coordinates (r, θ, ϕ) of the electron and characterized by the quantum numbers n, l and m_l . Here r is distance from nucleus, θ is colatitude and ϕ is azimuth. In the mathematical functions given in the table, Z is atomic number and a_0 is Bohr radius.

[JEE Adv. 2017]

Column 1	Column 2	Column 3
(I) 1s orbital	(i) $\psi_{n,l,m_l} \propto \left(\frac{Z}{a_0}\right)^{\frac{3}{2}} e^{-\left(\frac{Zr}{a_0}\right)}$	 (P)
(II) 2s orbital	(ii) One radial node	(Q) Probability density at nucleus $\propto \frac{1}{a_0^3}$
(III) $2p_z$ orbital	(iii) $\psi_{n,l,m_l} \propto \left(\frac{Z}{a_0}\right)^{\frac{5}{2}} r e^{-\left(\frac{Zr}{2a_0}\right)} \cos \theta$	(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

18. 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)

19. For He^+ ion, the only INCORRECT combination is

- (A) (II) (ii) (Q) (B) (I) (i) (S) (C) (I) (i) (R) (D) (I) (iii) (R)

20. For hydrogen atom, the only CORRECT combination is

- (A) (I) (iv) (R) (B) (I) (i) (P) (C) (II) (i) (Q) (D) (I) (i) (S)

21. For He^+ the electron is in orbit with energy equal to 3.4eV . The azimuthal quantum number for that orbit is 2 and magnetic quantum number is 0. Then which of the following is/are correct.

[JEE Adv. 2019]

- (a) The subshell is 4d.
 (b) The number of angular nodes in it is 2.
 (c) The numbers of radial nodes in it is 3.
 (d) The nuclear charge experienced in $n = 4$ is $2e$ less than that in $n = 1$, where e is electric charge.

22. The ground state energy of hydrogen atom is -13.6eV . Consider an electronic state Ψ of He^+ whose energy; azimuthal quantum number and magnetic quantum number are -3.4eV , 2 and 0, respectively. Which of the following statement(s) is(are) true for the state Ψ ?

[JEE Adv. 2019]

- (1) It has 2 angular nodes
 (2) It has 3 radial nodes
 (3) The nuclear charge experienced by the electron in this state is less than $2e$, where e is the magnitude of the electronic charge
 (4) It is a 4d state.

23. Answer the following by appropriately matching the lists based on the information given in the paragraph

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 showing how they depend on n .

[JEE Adv. 2019]

List-I

- (I) Radius of the n^{th} orbit
 (II) Angular momentum of the electron in the n^{th} orbit
 (III) Kinetic energy of the electron in the n^{th} orbit
 (IV) Potential energy of the electron in the n^{th} orbit

List-II

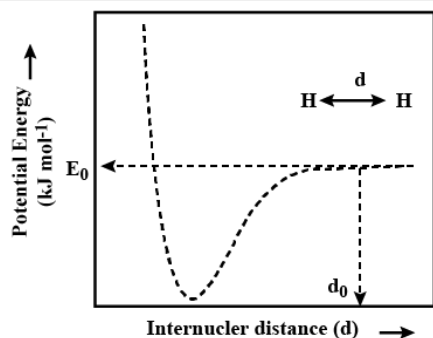
- (P) $\propto n^{-2}$
 (Q) $\propto n^{-1}$
 (R) $\propto n^0$
 (S) $\propto n^1$
 (T) $\propto n^2$
 (U) $\propto n^{1/2}$

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

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

24. The figure below is the plot of potential energy versus internuclear distance (d) of H_2 molecule in the electronic ground state. What is the value of the net potential energy E_0 (as indicated in the figure) in kJmol^{-1} , for $d = d_0$ at which the electron-electron repulsion and the nucleus-nucleus repulsion energies are absent? As reference, the potential energy of H atom is taken as zero when its electron and the nucleus are infinitely far apart. Use Avogadro constant as $6.023 \times 10^{23} \text{mol}^{-1}$.

[JEE Adv. 2020]



25. Consider a helium (He) atom that absorbs a photon of wavelength 330 nm. The change in the velocity (in cm s^{-1}) of the He atom after the photon absorption is

(Assume: Momentum is conserved when the photon is absorbed.)

Use: Planck constant = $6.6 \times 10^{-34} \text{ J s}$, Avogadro number = $6 \times 10^{23} \text{ mol}^{-1}$, Molar mass of He = 4 g mol^{-1}

[JEE Adv. 2021]

26. For He^* , a transition takes place from the orbit of radius 105.8 pm to the orbit of radius 26.45 pm. The wavelength (in nm) of the emitted photon during the transition is

[Use:

Bohr radius, $a = 52.9 \text{ pm}$

Rydberg constant, $R_H = 2.2 \times 10^{-18} \text{ J}$

Planck's constant, $h = 6.6 \times 10^{-34} \text{ J s}$

Speed of light, $c = 3 \times 10^8 \text{ ms}^{-1}$]

[JEE Adv. 2023]

ANSWER KEY

EXERCISE O-I

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

EXERCISE S-I

- | | | | |
|---|--|--|--------------------------------|
| 1. (2.7×10^{-14}) | 2. $(6.5 \times 10^{-15} \text{ m})$ | 3. (621.1 eV) | 4. (1.56×10^{16}) |
| 5. (200 watt.) | 6. (1.35×10^5) | 7. (10^{22}) | 8. (239.4 KJ/mol.) |
| 9. (1403 KJ/mol) | 10. (0.527) | 11. (6235 Å) | 12. (8.68%) |
| 13. (3×10^{22}) | 14. $(7.27 \times 10^5 \text{ m/s})$ | 15. $(-1.36 \times 10^{-19} \text{ Joules})$ | |
| 16. $(5.44 \times 10^5 \text{ m/s})$ | 17. (h/π) | 18. (2) | 19. (3) |
| 20. $(A = 2, B = 4)$ | 21. (12 V) | 22. (113.74 Å) | 23. $(10.2 \text{ eV}, z = 2)$ |
| 24. $(6530 \times 10^{12} \text{ Hz})$ | 25. $(\frac{9}{32})$ | 26. 8×10^6 | 27. (6) |
| 28. (4) | 29. (6) | 30. $(n = 4 \text{ to } n = 2)$ | |
| 31. $(v = 7.3 \times 10^{14} \text{ Hz, visible spectrum})$ | 32. $(1.827 \times 10^5 \text{ J/mol})$ | | |
| 33. (3) | 34. $(6563 \text{ Å}; 1216 \text{ Å}; 1026 \text{ Å})$ | 35. (8) | |
| 36. (20) | 37. $(4.5 \times 10^{14} \text{ s}^{-1})$ | 38. (31 nm) | 39. (319.2 KJ/mol) |
| 40. $(3.09 \times 10^8 \text{ cm/sec})$ | 41. (3.06 V) | 42. $(v_e = 1836 v_p)$ | 43. (6.15 Å) |
| 44. (4.71 Å) | 45. (0.0826 volts) | 46. $(3.68 \times 10^{-65} \text{ m})$ | |
| 47. $(\frac{20}{63})$ | 48. (5 Å) | 49. (3) | 50. (8) |
| 51. $(1.05 \times 10^{-13} \text{ m})$ | 52. (8) | 53. $(\approx 100 \text{ gm})$ | |
| 54. $(a)4, (b)2, (c)3, (d)1$ | 55. (11) | 56. (2) | 57. (1) |
| 58. $(\frac{9+3\sqrt{3}}{2} a_0)$ | | | |

EXERCISE O-II

1. (ABD) 2. (BCD) 3. (BD) 4. (AC) 5. (BC) 6. (BCD) 7. (BD)
8. (BCD) 9. (CD) 10. (ACD) 11. (ACD) 12. (B,C) 13. (CD) 14. (BC)
15. (B,C) 16. (B) 17. (A) 18. (D) 19. (A)-S, (B)-R, (C)-Q, (D)-P
20. (C) 21. (A)-P, (B)-P,Q,S, (C)-P, R (D)-Q,S 22. (A) 23. (C) 24. (A)
25. (B) 26. (A) 27. (A)

EXERCISE S-II

1. $\frac{188Ke^2}{m_\alpha v^2}$ 2. $6.4 \times 10^{-13} \text{ J}, 2.1 \times 10^{-13} \text{ J}, 3.4 \times 10^{-14} \text{ m}$
3. (a) $Z = 3$, (b) 122.4 eV & -244.8 eV , (c) 108.8 eV , (d) $1.013 \times 10^{-8} \text{ m}$, (e) 122.4 eV
4. $2; 9.75 \times 10^4 \text{ cm}^{-1}$ 5. $R\left(\frac{8}{9}\right)$ 6. $910 \text{ \AA}; \text{U.V.}$
7. $2.92 \times 10^{23} \text{ atoms}, 1.62 \times 10^{23} \text{ atoms}, 8.32 \times 10^2 \text{ KJ}$ 8. 2 to 6
9. 972.5 \AA 10. $303.89 \text{ \AA}, 2.645 \times 10^{-9} \text{ cm}$
11. 1,2,3,3 12. -435.2 eV
13. (a) 75 eV ; (b) 1.414 \AA ; (c) $2 \times 10^{-14} \text{ m}$ 14. (12)
15. $3.63 \times 10^6 \text{ m}^{-1}$ 16. 0.62 \AA 17. $E = \frac{n^6 h^6}{384 m^3 K^2 e^4 \pi^6}$
18. $\frac{1}{3} P = \frac{nhc}{\lambda t}$ 19. $3.3 \times 10^{-18} \text{ J}$ 20. 300303

JEE MAIN

1. (A) 2. (C) 3. (A) 4. (C) 5. (A) 6. (B) 7. (C)
8. (C) 9. (D) 10. (A) 11. (C) 12. (B) 13. (D) 14. (A)
15. (D) 16. (A) 17. (C) 18. (A) 19. (B) 20. (C) 21. (B)
22. (A) 23. (C) 24. (C) 25. (A) 26. (A) 27. (B) 28. (A)
29. (C) 30. (A) 31. (A) 32. (D) 33. (D) 34. (B) 35. (B)
36. (B) 37. (D) 38. (A) 39. (A) 40. (B) 41. (B) 42. (B)
43. (C) 44. (B) 45. (C) 46. (C) 47. (B) 48. (B) 49. (B)
50. (B) 51. (222.00) 52. (D) 53. (D) 54. (2) 55. (C) 56. (A)
57. (0) 58. (1758) 59. (548) 60. (D) 61. (B) 62. (C) 63. (B)

JEE ADVANCED

1. (D) 2. (D) 3. (C) 4. (D) 5. ((a) $r_0 = 2a_0$ (b) $6.626 \times 10^{-25} \text{ \AA}$)
6. ((a) $2.197 \times 10^6 \text{ m/s}$ (b) 3.31 \AA (c) $\sqrt{2} \cdot \frac{h}{2\pi}$) 7. (A) Q, (B) P, (C) R, (D) S
8. ((A) \rightarrow (Q,R); (B) \rightarrow (P,Q,R,S); (C) \rightarrow (P,Q,R); (D) \rightarrow (P,Q)) 9. (B) 10. (C)
11. (B) 12. (9) 13. (4) 14. (C) 15. (5) 16. (6) 17. (B)
18. (D) 19. (D) 20. (A,D) 21. (AB) 22. (1) 23. (B)
24. (-5242.42) 25. (30) 26. (30)

SOLUTION

EXERCISE O-I

Rutherford Model

1. $R = R_0 A^{1/3} = 1.3 \times 64^{1/3} = 5.2 \text{ fm}$
2. Rutherford's alpha particle scattering experiment eventually led to the conclusion electrons occupy space around the nucleus

Plancks quantum theory, number of photons

3. $\frac{E_1}{E_2} = \frac{\lambda_2}{\lambda_1} = \frac{4000}{2000} = \frac{2}{1}$
4. $\text{Power} = \frac{nhc}{\lambda \times t} \quad 40 \times \frac{80}{100} = \frac{n \times 6.62 \times 10^{-34} \times 3 \times 10^8}{620 \times 10^{-9} \times 20} \quad n = 2 \times 10^{21}$

Bohr's Model

5. $\frac{r_1}{r_2} = \frac{n_1^2}{n_2^2} = \frac{4}{1} \quad ; \quad \frac{n_1}{n_2} = \frac{2}{1}$
6. $r \propto \left(\frac{n^2}{Z} \right)$
7. $r_1 - r_2 = 24 \times (r_1)_H$
 $\frac{0.529 \times n_1^2}{1} - \frac{0.529 \times n_2^2}{1} = 24 \times 0.529$
 $\therefore (n_1^2 - n_2^2) = 24$
 So, $n_1 = 5$ and $n_2 = 1$
8. $E_n \text{ for } A^{+(Z-1)} = Z^2 \times E_n \text{ for } H$
9. $PE = -\frac{27.2 \times Z^2}{n^2} = -\frac{27.2}{n^2} - 3.02 \text{ eV}$
10. $E = 13.6 Z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] = 13.6 \times Z^2 \left[\frac{1}{4} - \frac{1}{9} \right] = 47.2 \text{ eV}$
11. $(E_2 - E_1) > (E_3 - E_2) > (E_4 - E_3)$
12. $\frac{E_1}{E_2} = \frac{Z_1^2}{Z_2^2}$

$$13. \quad E_{3-1} = E_{3-2} + E_{2-1}; \quad \frac{1}{\lambda_3} = \frac{1}{\lambda_2} + \frac{1}{\lambda_1}; \quad \nu_3 = \nu_2 + \nu_1$$

$$14. \quad \frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$$

$$15. \quad E = 13.6 Z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] = 13.6 \times 4 \left[\frac{1}{1} - \frac{1}{\infty} \right] = 54.4 \text{ eV}$$

$$E = 13.6 \times 4 \left[\frac{1}{4} - \frac{1}{\infty} \right] = 13.6 \text{ eV}$$

$$E = 13.6 \times 4 \left[\frac{1}{9} - \frac{1}{\infty} \right] = 6.04 \text{ eV}$$

$$16. \quad E = 13.6 Z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] = 13.6 \times 5^2 \left[\frac{1}{9} - \frac{1}{16} \right]$$

$$17. \quad E = 13.6 Z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$$

$$12.75 = 13.6 \times 5^2 \left[\frac{1}{1} - \frac{1}{n^2} \right]$$

$$18. \quad E = 13.6 Z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] = 13.6 \times 5^2 \left[\frac{1}{4} - \frac{1}{16} \right]$$

$$19. \quad L = \frac{nh}{2\pi}; \quad \frac{L_1}{L_2} = \frac{n_1}{n_2}$$

$$20. \quad \frac{r_1}{r_2} = \frac{n_1^2}{n_2^2} = \frac{R}{4R} \Rightarrow \frac{n_1}{n_2} = \frac{1}{2}$$

$$\therefore \frac{T_1}{T_2} = \frac{n_1^3}{n_2^3} = \frac{1}{8}$$

$$21. \quad \text{Angular momentum } L = mvr$$

$$J^2 = m^2 v^2 r^2$$

$$\text{or} \quad \frac{J^2}{2} = \left(\frac{1}{2} m v^2 \right) m r^2 \quad \text{or} \quad \text{K.E.} = \frac{J^2}{2 m r^2}$$

$$22. \quad IE_3 = 13.6 \times 96.3 \times Z^2 \text{ kJ/mol} = 13.6 \times 96.2 \times 9 \text{ kJ/mol} = 11775 \text{ kJ/mol}$$

$$\Delta H = IE_1 + IE_2 + IE_3$$

Spectrum

$$23. \quad E = 13.6 Z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]; \quad 13.6 \times 1 \times \left[\frac{1}{1} - \frac{1}{\infty} \right] = 13.6 \times Z^2 \left[\frac{1}{4} - \frac{1}{16} \right]$$

$$Z = 2$$

$$24. \quad 5 \rightarrow 2$$

$$25. \quad \text{Shortest wave length of Lyman series of H-atom, } \frac{1}{\lambda} = \frac{1}{x} = R \left[\frac{1}{(1)^2} - \frac{1}{(\infty)^2} \right]$$

$$\text{so, } x = \frac{1}{R}$$

$$\text{For Balmer series, } \frac{1}{\lambda} = R (1)^2 \left\{ \frac{1}{(2)^2} - \frac{1}{(3)^2} \right\}$$

$$\frac{1}{\lambda} = \frac{1}{x} \times \frac{5}{36} \quad \text{so, } \lambda = \frac{36x}{5}$$

$$26. \quad \frac{\frac{1}{\lambda_1} - \frac{1}{\lambda_2}}{\frac{1}{\lambda_3} - \frac{1}{\lambda_4}} = \frac{\left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]_1 - \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]_2}{\left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]_3 - \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]_4}; \quad \frac{\frac{1}{\lambda_1} - \frac{1}{\lambda_2}}{\frac{1}{\lambda_3} - \frac{1}{\lambda_4}} = \frac{\left[\frac{1}{1} - \frac{1}{4} \right]_1 - \left[\frac{1}{1} - \frac{1}{9} \right]_2}{\left[\frac{1}{1} - \frac{1}{9} \right]_3 - \left[\frac{1}{1} - \frac{1}{16} \right]_4}$$

$$27. \quad \frac{\bar{v}_1}{\bar{v}_2} = \frac{1 \times \left[\frac{1}{1} - \frac{1}{4} \right]}{4 \times \left[\frac{1}{4} - \frac{1}{16} \right]}; \quad \frac{\bar{v}_1}{\bar{v}_2} = \frac{1}{1}$$

28. The total number of lines belonging to Balmer series are two so, $n = 4$

$$\text{TE of electron} = \frac{13.6 \times 1}{16} = 0.85 \text{ eV.}$$

Then the kinetic energy of the ejected photoelectrons = $13 - 0.85 = 12.15 \text{ eV}$

$$29. \quad (n_2 + n_1) = 4 \text{ and } (n_2^2 - n_1^2) = 8, \text{ so, } n_1 = 1 \text{ and } n_2 = 3$$

$$\frac{1}{\lambda} = R_H Z^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right); \quad \frac{1}{\lambda} = R_H \times 4 \left(\frac{1}{1} - \frac{1}{9} \right)$$

$$\lambda = \frac{9}{32 R_H}$$

$$30. \quad \text{Total lines} = (n_2 - n_1) + (n_2 - n_1 - 1) + (n_2 - n_1 - 2) + \dots \\ = 1 + 2 + 3 \dots (x - 1)$$

31. Total spectral lines (without Balmer series) = $\frac{(n_2 - n_1)(n_2 - n_1 + 1)}{2} = \frac{(6-3)(6-3+1)}{2} = 6$

32. Total spectral lines in Bracket series = $10 - 4 = 6$

Photoelectric Effect

33. Photoelectric effect is a random phenomenon. So, electron It may come out with a kinetic energy less than $(h\nu - w)$ as some energy is lost while escaping out.

35. As the frequency of incident radiations increases, the kinetic energy of emitted photoelectrons increases.

Decreasing order of n : Violet > Blue > Orange > Red

Decreasing order of KE of photoelectrons : Violet > Blue > Orange > Red

36. $\frac{hc}{\lambda} = 1 + W \quad \dots(1)$

$3 \times \frac{hc}{\lambda} = 4 + W \quad \dots(2)$

from, e.q., (1) and (2) $f = 0.5 \text{ eV}$

37. The maximum KE of photoelectrons is corresponding to maximum stopping = 22 eV

$$E_{\text{incident}} = E_{\text{threshold}} + KE_{\text{max}} = 40 \text{ eV} + 22 \text{ eV} = 62 \text{ eV}$$

$$\lambda_{\text{incident}} = \frac{12400 \text{ Å}}{62} = 200 \text{ Å}$$

38. Energy of photon $E = \frac{12400}{\lambda} \text{ eV} = \frac{12400}{310} = 40 \text{ eV}$

$$E_{\text{incident}} = E_{\text{threshold}} + KE_{\text{max}}$$

$$40 = 12.8 + KE_{\text{max}} ; \quad KE_{\text{max}} = 27.8 \text{ eV} = 27.8 \times 1.6 \times 10^{-19} \text{ J}$$

$$KE = \frac{1}{2} mv^2 ; \quad 27.8 \times 1.6 \times 10^{-19} = \frac{1}{2} \times 9.1 \times 10^{-31} \times v^2$$

On solving, $v = 2.18 \sqrt{2} \times 10^6 \text{ m/s}$

39. $\lambda = \frac{h}{mv} = \frac{6.625 \times 10^{-34}}{0.2 \times 5} \times 3600 \approx 10^{-30} \text{ m.}$

40. KE of electron = $122.4 - 13.6 = 108.8 \text{ eV}$

$$41. \quad \frac{\lambda_y}{\lambda_x} = \frac{m_x v_x}{m_y v_y}; \quad \frac{\lambda_y}{1} = \frac{m_x v_x}{(0.25m_x)(0.75v_x)} = \frac{16}{3} = 5.33 \text{ \AA}$$

$$42. \quad \lambda_e : \lambda_p : \lambda_\alpha : \frac{1}{\sqrt{m_e \times 16E}} : \frac{1}{\sqrt{m_p \times 4E}} : \frac{1}{\sqrt{4m_p \times E}}$$

$$\text{So, } \lambda_e > \lambda_p = \lambda_\alpha$$

$$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mKE}} = \frac{h}{\sqrt{2mqV}}.$$

When v , KE and V are same, as m increasing, λ decreases. $\lambda_e > \lambda_p > \lambda_\alpha$ (if v , KE and V are same).

$$43. \quad 9.28 \times 10^{-8} \text{ m}$$

$$44. \quad \lambda = \frac{h}{mv} = \frac{6.62 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.2 \times 10^5}$$

$$45. \quad \text{Circumference} = 2\pi r = n\lambda$$

$$46. \quad \lambda = \frac{h}{\sqrt{2mqV}}$$

$$47. \quad \frac{hc}{\lambda} = E_1 - E_2 = KE_2 - KE_1$$

$$\therefore \lambda = \frac{h}{mV} \quad (mV)^2 = \left(\frac{h}{\lambda}\right)^2; \quad mV^2 = \frac{1}{2m} \frac{h^2}{\lambda^2}$$

$$\therefore \frac{hc}{\lambda} = \frac{h^2}{2m\lambda_2^2} - \frac{h^2}{2m\lambda_1^2}. \quad \therefore \lambda = \frac{2mc}{h} \left\{ \frac{\lambda_1^2 \lambda_2^2}{\lambda_1^2 - \lambda_2^2} \right\}.$$

$$48. \quad r_1 = 0.529 \text{ \AA}$$

$$r_3 = 0.529 \times (3)^2 \text{ \AA} = 9x$$

$$\text{so, } \lambda = \frac{2\pi r}{n} = \frac{2\pi(9x)}{3} = 6\pi x.$$

$$49. \quad \text{For an } \alpha\text{-particle accelerated with potential difference } V \text{ volt, } \lambda = \frac{h}{\sqrt{2mqV}} = \frac{0.101}{\sqrt{V}} \text{ \AA}$$

$$50. \quad \lambda \propto \frac{n}{Z}$$

Heisenberg Uncertainty Principle

$$51. \quad \Delta x = \frac{h}{4\pi m_e} \times \frac{1}{\Delta v} \quad \Delta v = v \times \frac{0.001}{100} = 300 \times 10^{-5} \text{ m/s}$$

$$\Delta x = 5.8 \times 10^{-5} \times \frac{1}{300 \times 10^{-5}} = 1.92 \times 10^{-2} \text{ m}$$

$$52. \quad P = \frac{h}{\lambda}; \quad dP = \frac{h}{\lambda^2} d\lambda$$

$$dx \times dP = \frac{h}{4\pi}; dx \times \frac{h}{\lambda^2} d\lambda = \frac{h}{4\pi}; \quad dx = \frac{\lambda^2}{4\pi} \times \frac{1}{d\lambda}$$

$$\text{Slope} = \frac{\lambda^2}{4\pi} = \frac{1}{\pi}; \quad \lambda^2 = 4 \text{ \AA}$$

$$\lambda = \sqrt{\frac{150}{V}} \text{ \AA}; \quad V = \frac{150}{4} = 37.5 \text{ V}$$

$$53. \quad d\lambda = \frac{\lambda^2}{4\pi} \times \frac{1}{dx}$$

$$54. \quad \lambda = \sqrt{\frac{150}{V}} \text{ \AA} = \sqrt{\frac{150}{6}} = 5 \text{ \AA}$$

$$P = \frac{h}{\lambda}; \quad dP = \frac{h}{\lambda^2} d\lambda$$

$$dx \times dP = \frac{h}{4\pi}; \quad dx \times \frac{h}{\lambda^2} d\lambda = \frac{h}{4\pi}; \quad d\lambda = \frac{\lambda^2}{4\pi} \times \frac{1}{dx}$$

Schrodinger Equation

56 The shape is given by l .

57 The s-orbital is symmetrical in all directions.

58 xz plane is the nodal plane for p_y -orbital.

59 The p-orbital has only one nodal plane.

60 Theoretical

61 Number of radial nodes = $n - l - 1$.

62 Number of nodal surface of s-orbital = $n - 1$

63 Number of radial nodes = $n - l - 1 = 3 - 2 - 1 = 0$

64. Probability of finding electron at the nucleus = 0

65.
$$L = \sqrt{\ell(\ell+1)} \frac{h}{2\pi} = \sqrt{2(2+1)} \frac{h}{2\pi} = \sqrt{6} \frac{h}{2\pi}$$

66. Number of radial node = $n - \ell - 1 = 1$

So, $\ell = 1$;
$$L = \sqrt{\ell(\ell+1)} \frac{h}{2\pi} = \sqrt{2} \frac{h}{2\pi}$$

67. sign of the wave function



EXERCISE S-I

Rutherford Model

$$1. \quad \text{Fraction occupied} = \frac{\frac{4}{3}\pi(1.5 \times 10^{-15})^3}{\frac{4}{3}\pi(0.05 \times 10^{-9})^3} = 2.7 \times 10^{-14}$$

$$2. \quad (A) \quad R = R_0 (A)^{\frac{1}{3}}$$

$$= 1.3 \times 10^{-15} \times (125)^{\frac{1}{3}}$$

$$\Rightarrow R = 6.5 \times 10^{-15} \text{ m.}$$

Plancks Quantum theory, Number of Photons

$$3. \quad E = \frac{12400 \text{ eV } \text{\AA}}{\lambda (\text{\AA})}$$

$$= \frac{12400}{2000} \times 100$$

$$= 620$$

$$4. \quad 5 \times 10^{-3} = \frac{12400}{6200} \times 1.6 \times 10^{-19} \times N$$

$$\Rightarrow N = \frac{5 \times 10^{-3}}{2 \times 1.6 \times 10^{-19}}$$

$$\Rightarrow N = 1.56 \times 10^{16}$$

$$5. \quad 100 = N \times \frac{hc}{8000} \quad \dots\dots\dots(1)$$

$$x = N \times \frac{hc}{4000} \quad \dots\dots\dots(2)$$

Divide (1) & (2)

$$\frac{100}{x} = \frac{4000}{8000}$$

$$\Rightarrow x = 200 \text{ watt.}$$

$$6. \quad 3.15 \times 10^{-14} = N \times \frac{12400}{8500} \times 1.6 \times 10^{-19}$$

$$\Rightarrow N = \frac{3.15 \times 10^{-14} \times 8500}{12400 \times 1.6 \times 10^{-19}}$$

$$\Rightarrow N = 1.34 \times 10^5$$

7. $330 = N \times 6.625 \times 10^{-34} \times 5 \times 10^{13}$

$$\Rightarrow N = \frac{330}{6.625 \times 10^{-34} \times 5 \times 10^{13}}$$

$$\Rightarrow N = 10 \times 10^{21}$$

$$\Rightarrow N = 10^{22}$$

8. $E = \frac{12400}{5000} \times 1.6 \times 10^{-19} \times 6.023 \times 10^{23}$

$$= 239.4 \times 10^3 \text{ J/mole.}$$

$$\Rightarrow E = 239.4 \text{ KJ/mole.}$$

9. $E = \frac{12400}{854} \times 1.6 \times 10^{-19} \times 6.023 \times 10^{23} \times 10^{-3}$

$$\approx 1403 \text{ KJ/mole.}$$

10. Let number quanta emitted = n_1

Let number of quanta absorbed = n_2

$$\Rightarrow n_1 \times \frac{hc}{5080 \times 10^{-10}} = n_2 \times \frac{hc}{4530 \times 10^{-10}} \times 0.47$$

$$\Rightarrow \frac{n_1}{n_2} = \frac{5080}{4530} \times 0.47$$

$$\Rightarrow \frac{n_1}{n_2} = 0.527$$

11. $192 \times 10^3 = \frac{12400 \times 1.6 \times 10^{-19}}{\lambda} \times 6.022 \times 10^{23}$

$$\Rightarrow \lambda = \frac{12400 \times 1.6 \times 10^{-19} \times 6.023 \times 10^{23}}{192 \times 10^3}$$

$$\Rightarrow \lambda = 6235 \text{ Å}$$

12. $h\nu = h\nu_0 + K. E.$

$$\left(\frac{12400 \times 6 \times 10^{23}}{253.7} \times 1.6 \times 10^{-20} \right) = 430.53 + \text{K. E.}$$

$$\Rightarrow \text{K.E.} = 469.21 - 430.53$$

$$= 38.68$$

$$\Rightarrow \% \text{ of energy converted into K.E.}$$

$$= \left(\frac{38.68}{469.21} \times 100 \right)$$

$$= 8.68 \%$$

13. Quantum yield = $\frac{\text{no. of molecules reacting}}{\text{no. of quanta absorbed or photons}}$

$$\Rightarrow \text{number of photons absorbed} = \frac{0.01 \times 6 \times 10^{23}}{0.2} = 3 \times 10^{22}$$

Bohr's Model

14. $V_n = 2.18 \times 10^6 \times \frac{Z}{n} \text{ m/s}$

$$\Rightarrow V_3 = 2.18 \times 10^6 \times \frac{1}{3}$$

$$\Rightarrow V_3 = 7.27 \times 10^5 \text{ m/s.}$$

15. $r_n = 16 \times 0.529$

$$0.529 \times \frac{n^2}{1} = 16 \times 0.529$$

$$\Rightarrow n = 4$$

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

$$\Rightarrow E_4 = -0.85 \times 1.6 \times 10^{-19} \text{ J}$$

$$\Rightarrow E_4 = -1.36 \times 10^{-19} \text{ J}$$

16. $r_n = 0.85 \times 10^{-9} \text{ m.}$

$$0.529 \times \frac{n^2}{1} = 8.5 \text{ \AA}$$

$$\Rightarrow n = 4$$

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

$$\Rightarrow V_4 = 2.18 \times 10^6 \times \frac{1}{4} \text{ m/s}$$

$$\Rightarrow V_4 = 5.45 \times 10^5 \text{ m/s.}$$

$$17. \quad \vec{L} = \frac{nh}{2\pi}$$

$$\text{as, } n = 2$$

$$\Rightarrow \text{Angular momentum} = \left(\frac{h}{\pi} \right)$$

$$18. \quad \text{K.E.} = \frac{k \cdot z e^2}{zr}$$

$$\text{Log (k.e.)} = \log + \left(\frac{ke^2}{zr} \right) \log z$$

$$\text{Now, } \frac{k \cdot e^2}{zr} = 3.4$$

$$\text{T.E} = - \frac{k \cdot z \cdot e^2}{zr}$$

$$\text{as, } Z = 1$$

$$\Rightarrow \text{T.E} = 3.4 \text{ eV}$$

$$\Rightarrow n = 2$$

$$19. \quad 30 = N_1 \times 13.6 \times (1)^2 \quad \dots\dots(1)$$

$$40 = N_2 \times 13.6 \times (2)^2 \quad \dots\dots(2)$$

Divide (1) & (2),

$$\frac{30}{40} = \frac{N_1}{N_2} \times \frac{1}{4}$$

$$\Rightarrow \frac{N_1}{N_2} = 3$$

$$20. \quad \Delta E 2.55 \quad \text{i.e.} \quad E_4 - E_2 = 2.55$$

\Rightarrow orbit number of states A & B are 2 & 4.

$$22. \quad \frac{1}{\lambda} = RZ^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

$$\Rightarrow \frac{1}{\lambda} = 1.09 \times 10^7 \times 9 \times \frac{8}{9}$$

$$\Rightarrow \lambda = 113.63 \text{ \AA}$$

23. $\Delta E_{2 \rightarrow 1} = 10.2 \text{ eV}$

$$\frac{1}{3 \times 10^{-8}} = 1.1 \times 10^7 \times Z^2 \left(\frac{1}{1} - \frac{1}{4} \right)$$

$$\Rightarrow Z = 2 \quad \text{i.e. He}^+.$$

24. $V = \frac{V}{2\pi r}$

$$= \frac{2.18 \times 10^6 \times 10^{10}}{2 \times 3.14 \times 0.529}$$

$$\Rightarrow V = 6530 \times 10^{12} \text{ Hz}$$

25. $\frac{T_2}{T_4} = \frac{\left(\frac{2\pi r}{v} \right)_{(\text{He}^+)}}{\left(\frac{2\pi r}{v} \right)_{(\text{Li}^{+2})}} = \frac{.529 \times \frac{4}{2} \times \frac{2}{2.18 \times 10^6 \times 2}}{.529 \times \frac{16}{3} \times \frac{4}{2.18 \times 10^6 \times 3}}$

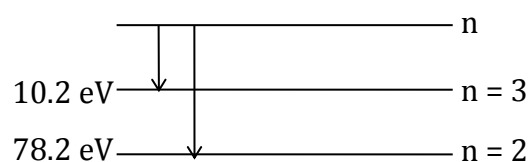
$$\Rightarrow \frac{T_2}{T_4} = \frac{9}{32}$$

26. $T = \frac{2\pi r}{v} = \frac{2 \times 3.14 \times 0.529 \times 4 \times 10^{-10} \times 2}{2.18 \times 10^6 \times 1}$

$$= 12.19 \times 10^{-16}.$$

$$\Rightarrow \text{Number of orbits} = \frac{10^{-8}}{12.19 \times 10^{-16}}$$

$$= 8 \times 10^6$$



27.

$$\Delta E = 68 \text{ eV} = 13.6 \times Z^2 \left(\frac{1}{4} - \frac{1}{9} \right)$$

$$\Rightarrow Z = 6$$

Spectrun

28. 4 spectral lines are possible

i.e. $7 \rightarrow 3$

$6 \rightarrow 3$

$5 \rightarrow 3$

& $4 \rightarrow 3$.

29. $\frac{\Delta n(\Delta n + 1)}{2} = 6$

$\Rightarrow \Delta n = 4 \text{ or } 3$

Also $\Delta n = n_2 - n_1$

$\Rightarrow n_2 = 6$.

30. $R \times 4 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right) = R \times 1 \times \left(\frac{1}{1} - \frac{1}{4} \right)$

$\Rightarrow \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right) = \left(\frac{1}{4} - \frac{1}{10} \right) = \left(\frac{1}{(2)^2} - \frac{1}{(4)^2} \right)$

$\Rightarrow n_1 = 2 \text{ \& } n_2 = 4$

\Rightarrow Transition is from $(n = 4)$ to $(n = 2)$

31. $\frac{1}{\lambda} = 1.1 \times 10^7 \times 1 \left(\frac{1}{4} - \frac{1}{36} \right) = 1.1 \times 10^7 \times \frac{8}{36}$

Now. $v = \frac{c}{\lambda} = \left(\frac{3 \times 10^8 \times 1.1 \times 10^7 \times 8}{36} \right) \Rightarrow v = 7.3 \times 10^{14} \text{ Hz}$

It will lie in visible spectrum.

32. $\Delta E = 1.89 \times 6.022 \times 10^{23} \times 1.6 \times 10^{-19} = 1.82 \times 10^5 \quad 5/\text{mole.}$

33. 3 Spectral lines are possible

i.e. $3 \rightarrow 1$;

$2 \rightarrow 1 \text{ \& }$

$3 \rightarrow 2$

34. $\Delta E = 12.08 \text{ er}$

Possible transitions are from ($n = 3$ to $n = 1$), ($n = 3$ to $n = 2$) & ($n = 2$ to $n = 1$)

$\Rightarrow \lambda$ emitted :

$$(1) (n = 3) \text{ to } (n = 1) \Rightarrow \lambda = 1026 \text{ \AA}$$

$$(2) (n = 3 \text{ to } n = 2) \Rightarrow \lambda = 6563 \text{ \AA}$$

$$(3) (n = 2 \text{ to } n = 1) \Rightarrow \lambda = 1216 \text{ \AA}$$

respectively .

$$35. \quad DE = \frac{3}{4} \times 0.85$$

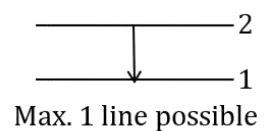
$$\Rightarrow \Delta E = \frac{3}{4} \times \frac{13.6}{(4)^2}$$

$$\text{Or, } DE = \frac{13.6}{(4)^2} \left(\frac{1}{1} - \frac{1}{4} \right)$$

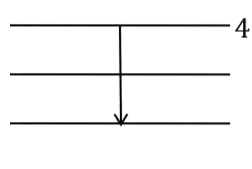
$$\Rightarrow DE = 13.6 \left(\frac{1}{(4)^2} - \frac{1}{(8)^2} \right)$$

Thus, this photon corresponds to transition from ($n = 8$) to ($n = 4$) $\therefore (x = 8)$

36.



For $2 \rightarrow 1$ Transition

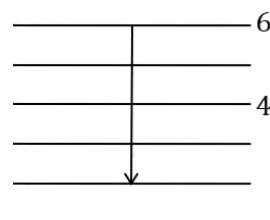


He⁺ion

$$\text{Max. } \frac{4(4-1)}{2} \text{ i.e. } 6$$

lines possible for

$4 \rightarrow 1$ transition.



Li⁺ion

$$\text{Max. } \frac{6(6-1)}{2} \text{ i.e. } 15$$

lines possible for

$6 \rightarrow 1$ transition.

But, $(H_2)_{2 \rightarrow 1} = (He^+)_{4 \rightarrow 2} = (Li^{+2})_{6 \rightarrow 3}$ are lines of same energy & 12 each other.

$$\Rightarrow \text{Total lines observed} = (1+6+15) - 2 = 20$$

Photoelectric Effect

$$37. \quad V = \left(\frac{180.69 \times 10^3}{6.625 \times 10^{-34} \times 6.022 \times 10^{23}} \right)$$

$$\Rightarrow V = 4.5 \times 10^{14} \text{ V}$$

$$38. \quad \phi = 40 \text{ eV} = h\nu_0$$

$$40 \times 1.6 \times 10^{-19} = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{\lambda_0}$$

$$\Rightarrow \lambda_0 = 31 \text{ nm}$$

$$39. \quad \phi = 0.8 \times 10^{15} \times 6.625 \times 10^{-34} \times 6.022 \times 10^{23}$$

$$\Rightarrow \phi = 319.2 \text{ KJ/mole}$$

$$* \quad h \times 3.2 \times 10^{15} = \phi + 2 \text{ K.E.}$$

$$h \times 2 \times 10^{15} = \phi + \text{K.E.}$$

$$\Rightarrow \text{K.E.} = (1.2 \times 10^{15}) \times h$$

$$40. \quad \Delta E = 270 \text{ eV} = \text{K.E.} = \frac{1}{2} mv^2 \Rightarrow V = 3.09 \times 10^8 \text{ cm/sec.}$$

41. Stopping potential will be 3.06 Volt

$$42. \quad \frac{\lambda_e}{\lambda_p} = \frac{m_p v_p}{m_e v_e}$$

$$\Rightarrow \frac{\lambda_e}{\lambda_p} = \frac{1836 v_p}{v_e}$$

$$\Rightarrow v_e = 1836 v_p$$

$$43. \quad \lambda = \sqrt{\frac{150}{4}} \text{ \AA}$$

$$\Rightarrow \lambda = 6.135 \text{ \AA}$$

$$44. \quad \lambda = \frac{12.27}{\sqrt{6.8}} \text{ \AA}$$

$$\Rightarrow \quad \lambda = 4.71 \text{ \AA}$$

$$45. \quad \lambda = \frac{h}{\sqrt{2.m.e.v}}$$

$$\Rightarrow \quad V = \frac{h^2}{2.m.e.\lambda^2}$$

$$\Rightarrow \quad V = 0.08 \text{ volt.}$$

$$46. \quad \text{As,} \quad \lambda = \frac{h}{m.v.}$$

$$\Rightarrow \quad \lambda = \frac{6.625 \times 10^{-34}}{6 \times 10^{24} \times 3 \times 10^6}$$

$$\Rightarrow \quad \lambda = 3.68 \times 10^{-65} \text{ m.}$$

$$47. \quad \frac{\lambda_3 - \lambda_2}{\lambda_1}$$

$$= \quad \frac{\frac{1}{7} - \frac{1}{9}}{\frac{1}{10}}$$

$$\Rightarrow \quad \frac{\lambda_3 - \lambda_2}{\lambda_1} = \frac{20}{63}.$$

$$48. \quad 0.85 \times 4 = 1.4 \times \text{K. E.}$$

$$\Rightarrow \quad \text{K. E.} = 2 \text{ eV}$$

$$\text{Total K. E.} = 6 \text{ eV}$$

$$\Rightarrow \quad \lambda = 5 \text{ \AA}$$

$$49. \quad (n = 6) \text{ to } (n = 1)$$

$$\Rightarrow \quad \text{Number of paschen lines emitted are,}$$

$$6 \rightarrow 3$$

$$5 \rightarrow 3 \quad \text{i.e.} \quad 3 \text{ lines}$$

$$4 \rightarrow 3$$

$$50. \quad a \times \pi \times 0.529 = \frac{h}{m v}$$

$$\Rightarrow \quad a = \frac{6.626 \times 10^{-34} \times 4}{3.14 \times 0.529 \times 9.1 \times 10^{-31} \times 2.18 \times 10^6}$$

$$\Rightarrow \quad a = 8$$

Heisenberg Uncertainty Principle

$$51. \quad \Delta x = \frac{h}{4\pi m \Delta v}$$

$$\Rightarrow \quad \Delta x = 1.05 \times 10^{-13}$$

$$52. \quad \Delta x = \Delta p$$

$$\Delta v \rightarrow ?, \quad \text{As,} \quad \Delta x \cdot \Delta p = \frac{h}{4\pi}$$

$$\Rightarrow \quad m^2 \cdot \Delta v^2 = \frac{h}{4\pi}$$

$$\Rightarrow \quad \Delta v = \sqrt{\frac{h}{4\pi}} \times \frac{1}{m}$$

$$\Rightarrow \quad \Delta v = 8 \times 10^{12}$$

$$\Rightarrow \quad x = 8$$

$$53. \quad \Delta x \cdot \Delta p \geq \frac{h}{4\pi}$$

$$\Rightarrow \quad m = 100 \text{ g}$$

Schrodinger Wave Equation and Orbital Concept

$$54. \quad (a) \quad 5s \rightarrow R. N \rightarrow 4$$

$$(b) \quad 3 d_{yz} \rightarrow A. N \rightarrow 2$$

$$(c) \quad 4 d_{xy} \rightarrow (R. N + A. N) = (1+2) = 3$$

$$(d) \quad 3p \rightarrow A. N = 1$$

$$55. \quad (n \leq 4) \quad \& \quad 2 \text{ possible subshell} = 3p, 4p \text{ and } 4d$$

$$56. \frac{A.N_{3d}}{(A.N)_{3p}} = \frac{x}{1} = \frac{2}{1}$$

$$\Rightarrow x = 2$$

57. For 2S, only 1 Radial node.

$$\Rightarrow \text{value of } x = 1$$

58. At node, $R = 0$

$$\Rightarrow \sigma^2 - 6\sigma + 6 = 0$$

$$\Rightarrow \sigma = \left(\frac{9+3\sqrt{3}}{2} \right) a_0 \quad \& \quad \left(\frac{9+3\sqrt{3}}{2} \right) a_0.$$

EXERCISE O-II

$$3. \quad v = \frac{c}{\lambda} = \frac{3 \times 10^8}{600 \times 10^{-9}} = 5 \times 10^{14} \text{ sec}^{-1}; \quad E = \frac{12400}{6000} = 2.07 \text{ eV}.$$

$$5. \quad \text{Angular momentum} = \frac{nh}{2\pi}$$

$$\text{Change in angular momentum for } 3 \rightarrow 2 \text{ transition} = (3 - 2) \frac{h}{2\pi} = \frac{h}{2\pi}.$$

$$\text{Change in angular momentum for } 4 \rightarrow 2 \text{ transition} = (4 - 2) \frac{h}{2\pi} = \frac{h}{\pi}.$$

$$6. \quad \text{1st excitation potential} = 10.2 Z^2 = 24 \text{ V} \quad \therefore Z^2 = 24/10.2$$

$$\therefore IE = 13.6 Z^2 = \frac{13.6 \times 24}{10.2} = 32 \text{ eV}.$$

$$\text{Binding energy of 3rd excited state} = 0.85 Z^2 = \frac{0.85 \times 24}{10.2} = 2 \text{ eV}.$$

$$2^{\text{nd}} \text{ excitation potential of sample} = 12.09 Z^2 = \frac{12.09 \times 24}{10.2} = \frac{32 \times 8}{9} \text{ V}.$$

7. Transition is taking place from $6 \rightarrow 2$

$$\Rightarrow \Delta n = 4$$

$$\text{Hence maximum number of spectral line observed} = \frac{4(4+1)}{2} = 10.$$

Number of lines belonging to the Balmer series = 4 ($6 \rightarrow 2, 5 \rightarrow 2, 4 \rightarrow 2, 3 \rightarrow 2$)

Number of lines belonging to Paschen series = 3 ($6 \rightarrow 3, 5 \rightarrow 3, 4 \rightarrow 3$).

9. The difference in angular momentum associated with the electron present in consecutive orbits of H-atom = $(n_2 - n_1) \frac{h}{2\pi}$
13. Radial distribution function ($\Psi^2 \cdot 4\pi r^2 dr$) give probability at a particular distance along all the direction spherically
 $\Psi^2(r)$ give only radial probability density at a particular distance over a spherical surface
14. Number of maxima when a curve is plotted between $4\pi r^2 R^2(r)$ vs r are '2' because it has two radial nodes.
16. Statement (2) alone is sufficient to concludes that its not $3p_x$ orbital because $3p_x$ orbital has one angular node.
19. **Column-I** **Column-II**
- (A) $\lambda = \sqrt{\frac{150}{V}} \text{ \AA} = \sqrt{\frac{150}{13.6}} \text{ \AA}$ (B) $v = \frac{2.188 \times 10^6 \times Z}{n} = \frac{2.188 \times 10^6}{3} \text{ m/sec}$
- (C) $TE = -\frac{13.6 \times Z^2}{n^2} = -13.6 \times 9 \text{ eV}$ (D) $r = \frac{0.529 \times n^2}{Z} \text{ \AA} = 0.529 \text{ \AA}$
20. (a) Energy of ground state of He^+ = $-13.6 \times 2^2 = -54.4 \text{ eV}$ (iv)
 (b) Potential energy of I orbit of H-atom = $-27.2 \times 1^2 = -27.2 \text{ eV}$ (ii)
 (c) Kinetic energy of II excited state of He^+ = $13.6 \times \frac{2^2}{3^2} = 6.04 \text{ eV}$ (i)
 (d) Ionisation potential of He^+ = $13.6 \times 2^2 = 54.4 \text{ V}$ (iii)
21. (A) s-orbital ; $r = 0, \psi \neq 0$ and 3 radial nodes ; 4s
 (B) 3 radial nodes (s, p, d) ; 4s, $5p_x$ $6d_{xy}$
 (C) Angular probability is dependent of q and f for $5p_y$, $6d_{xy}$
 (D) At least one angular node ; $5p_x$ (1); $6d_{xy}$ (2)
22. $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mKE}}$
 When v , KE and V are same, as m increasing, λ decreases. $\lambda_H > \lambda_D > \lambda_T$
23. $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mKE}}$
24. $\Delta x \Delta p = \frac{h}{4\pi} \Rightarrow \Delta p^2 = \frac{h}{4\pi} \Rightarrow m^2 \Delta v^2 = \frac{h}{4\pi} \Rightarrow \Delta v = \frac{1}{2m} \sqrt{\frac{h}{\pi}}$
25. Multiply angular part and radial part of 1s orbital and square this.



27. s- orbital is spherically symmetric.



EXERCISE-(S - II)

1. $R = \frac{4k.z.e.^2}{m\alpha.v^2}$

$$= \frac{4k.47.e^2}{m\alpha.v^2}$$

$$\Rightarrow R = \frac{188.k.e^2}{m\alpha.v^2}$$

2. Potential difference = 2×10^6 V; Charge of alpha particle = $2e$; Charge of silver = $47e$

KE of alpha particle = $qV = 2 \times 1.6 \times 10^{-19} \times 2 \times 10^6 = 6.4 \times 10^{-13}$ J

K.E at A = K.E at B + P.E at B

$$6.4 \times 10^{-13} = \text{K.E at B} + \frac{9 \times 10^9 \times 2 \times 1.6 \times 10^{-19} \times 47 \times 10^{-19}}{5 \times 10^{-14}}$$

K.E at B = 2.1×10^{-13} joules

3. (a) $2.55 z^2 = 16.52$

$$\Rightarrow z = 3$$

(b) $\text{K.E} = \frac{k.z.e^2}{zr}$

$$= \frac{9 \times 10^9 \times 3 \times (1.6 \times 10^{-19})^2}{2 \times 0.529 \times 10^{-10}}$$

$$\Rightarrow \text{K.E} = 122.9 \text{ eV}$$

& P.E = $\ominus 244.8 \text{ eV}$

(d) $\Delta E_{2 \rightarrow 3} = 12.17^2$

$$= 12.1 \times 9$$

$$= 108.9 \text{ eV}$$

(d) $\frac{1}{\lambda} = R.z^2 \left(\frac{1}{1^2} - \frac{1}{\infty^2} \right)$

$$\Rightarrow \lambda = \frac{1}{R.z^2} = \frac{1}{1.1 \times 10^7 \times 9}$$

$$\Rightarrow \lambda = 1.013 \times 10^{-8} \text{ m.}$$

(e) $\text{K.E} = \frac{k.z.e^2}{zr}$

$$\Rightarrow \text{K.E} = 122.4 \text{ eV.}$$

$$4. \quad \frac{V_{n_1}}{V_c} = \frac{1}{275}$$

$$\Rightarrow \frac{2.18 \times 10^6 \times 1}{n \times 3 \times 10^8} = \frac{1}{275}$$

$$\Rightarrow n = 2$$

$$\text{now } \bar{V} = \frac{1}{\lambda} = R Z^2 \left(\frac{1}{1} - \frac{1}{9} \right)$$

$$\frac{1}{\lambda} = 1.09 \times 10^7 \times 8/9$$

$$\Rightarrow \frac{1}{\lambda} \text{ i.e. } \bar{V} = 9.68 \times 10^4 \text{ cm}^{-1}$$

$$5. \quad L = \frac{n \times 6.625 \times 10^{-34}}{2 \times 3.14}; \quad n = 3$$

$$\frac{1}{\lambda} = R \left[\frac{1}{1^2} - \frac{1}{3^2} \right] = R \left(\frac{8}{9} \right)$$

$$6. \quad \text{IE} = 13.6 \text{ eV}; \quad \lambda = \frac{12400}{13.6} = 910 \text{ \AA}$$

$$7. \quad \text{(i) Total number of H atoms} = 1.8 \times 6.023 \times 10^{23} = 1.084 \times 10^{24}$$

$$\text{Number of H atoms in 2nd energy level} = 0.15 \times 1.08 \times 10^{24} = 1.62 \times 10^{23} \text{ atoms,}$$

$$\text{Number of H atoms in 3rd energy level} = 0.27 \times 1.08 \times 10^{24} = 2.92 \times 10^{23} \text{ atoms,}$$

(ii) Energy evolved for $n = 2 \rightarrow 1$

$$E_1 = 21.7 \times 10^{-12} \times \left[\frac{1}{1} - \frac{1}{4} \right] = 1.63 \times 10^{-11}$$

Energy evolved for $n = 3 \rightarrow 1$

$$E_2 = 21.7 \times 10^{-12} \times \left[\frac{1}{1} - \frac{1}{9} \right] = 1.93 \times 10^{-11}$$

$$\text{Total energy} = 1.63 \times 10^{-11} \times 1.62 \times 10^{23} + 1.93 \times 10^{-11} \times 2.92 \times 10^{23} = 8.32 \times 10^{12} \text{ erg} = 8.32 \times 10^2 \text{ KJ}$$

8. Energy of emitted photons can not be greater than 13.6 eV (otherwise He^+ will ionise)

therefore single electron specie must be hydrogen energy emitted = $E_3 - E_1$

$$= -1.51 + 13.6 = 12.09$$

For He^+ ion this energy corresponds to excitation from 2 to 6.

$$9. \quad E = 13.6 \times \left(\frac{1}{1} - \frac{1}{16} \right) \text{ eV} = 12.75 \text{ eV}$$

$$\lambda = \frac{12400}{12.75} = 972.5 \text{ \AA}$$

$$10. \quad R_H = 2.18 \times 10^{-18}$$

$$E_2 - E_1 = \frac{hc}{\lambda}$$

$$E_1 = -4R_H = -4R_H$$

$$E_2 = \frac{-4R_H}{4} = -R_H$$

$$E_2 - E_1 = 3R_H = 3 \times 2.18 \times 10^{-18} \text{ J} = \frac{hc}{\lambda}$$

$$\lambda = 303.89 \times 10^{-10} \text{ m}$$

$$11. \quad (i) \quad \frac{U}{K} = \frac{-\frac{27.2 \times Z^2}{n^2}}{\frac{13.6 \times Z^2}{n^2}}; \quad \frac{-8}{1} = \frac{-\frac{27.2 \times 4}{1^2}}{\frac{13.6 \times Z^2}{1^2}}; \quad Z = 1$$

$$(ii) \quad \frac{r_1}{r_2} = \frac{\left[\frac{n^2}{Z} \right]_1}{\left[\frac{n^2}{Z} \right]_2}; \quad \frac{1}{8} = \frac{\left[\frac{1^2}{Z} \right]_1}{\left[\frac{2^2}{1} \right]_2}; \quad Z = 2$$

$$12. \quad TE = -\frac{2\pi^2 K^2 Z^2 e^4 m}{n^2 h^2} = -\frac{2\pi^2 K^2 Z^2 (2e)^4 (2m)}{n^2 h^2}$$

$$= 32 \times \left[-\frac{2\pi^2 K^2 Z^2 (e)^4 (m)}{n^2 h^2} \right] = 32 \times (-13.6) = -435.2 \text{ eV}$$

$$13. \quad (a) \quad E_{\text{photon}} = W + KE_{\text{max}}; \quad E_{\text{photon}} = \frac{1240}{12.4} = 100 \text{ eV}; \quad KE_{\text{max}} = 75 \text{ eV}$$

$$(b) \quad \lambda = \sqrt{\frac{150}{V}} \text{ \AA} = \sqrt{\frac{150}{75}} = 1.414 \text{ \AA}$$

$$(c) \quad P = \frac{h}{\lambda}; \quad dP = \frac{h}{\lambda^2} d\lambda$$

14. For an electron, de-Broglie wavelength $\lambda = \sqrt{\frac{150}{KE_{\text{eV}}}} \text{ \AA}$

$$\lambda^2 = \frac{150}{KE_{\text{eV}}}; \quad KE = \frac{150}{\lambda^2} = \frac{150}{12.016} = \frac{13.6 \times 11}{144} \text{ eV (Using given relation)}$$

$$(E_{n_2 \rightarrow 6})_{\text{Li}^{2+}} = (E_{3 \rightarrow \infty})_{\text{H}} + KE_{\text{electron}}$$

$$13.6 (3)^2 \left(\frac{1}{6^2} - \frac{1}{n_2^2} \right) = 13.6 (1)^2 \left[\frac{1}{3^2} - \frac{1}{\infty^2} \right] + \frac{13.6 \times 11}{144}$$

On solving, we get $n_2 = 12$.

15. $4.5 = \frac{12400}{\lambda(\text{\AA})}$

$$\lambda(\text{\AA}) = \frac{12400}{4.5}$$

$$\Rightarrow \lambda = 2755.56 (\text{\AA})$$

$$\bar{\nu} = \frac{1}{\lambda} = \frac{10^{10}}{2755.56}$$

$$\Rightarrow \bar{\nu} = 3.63 \times 10^6 \text{ m}^{-1}$$

16. $E = \frac{hc}{\lambda}$

$$\lambda = \frac{10^{10}}{2755.56}$$

$$\Rightarrow \lambda = 0.62 \text{ \AA}$$

17. Since H atom is a bounded system U cannot be positive

$$U = -\frac{ke^2}{3r^3}; \quad F = -\frac{dU}{dr} = -\frac{ke^2}{r^4} \dots\dots\dots 1$$

$$\frac{mv^2}{r} = \frac{ke^2}{r^4}; \quad mv^2 = \frac{ke^2}{r^3}; \quad KE = \frac{1}{2}mv^2 = \frac{ke^2}{2r^3}$$

$$TE = KE + U = \frac{ke^2}{2r^3} - \frac{ke^2}{3r^3} = -\frac{ke^2}{6r^3}$$

18. $\frac{1}{3}P = \frac{nhc}{\lambda t}$

$$\text{Number of photoelectrons emitted} = \frac{90}{3} \times \frac{4000 \times 10^{-10}}{6.4 \times 10^{-34} \times 3 \times 10^8}$$

$$\text{Magnitude of charge passing per second} = \frac{1}{1.6} \times 10^{20} \times 1.6 \times 10^{-19} = 10 \text{ A}$$

19. He atom can be excited to $1s^1 2p^1$ by $\lambda = 58.44 \text{ nm}$. If lowest excited state for He lies 4857 cm^{-1} below the above. Calculate the energy for the lower excitation state.

20. A ; $n - \ell - 1 = 2$, but $\ell = 0$, so value of $n = 3$

B ; This equation belongs to s-orbital so, number of angular nodes = 0

C ; This equation belongs to s-orbital so, $\ell = 0$

D ; 8s, 7p, 6d, 5f and 8p

E ; Orbital angular momentum = 0, because $\ell = 0$.

F ; $r^2 - 5k_3r + 6k_3^2 = 0$

So, $r = 3$ and 2 , but for farthest node $r = 3$

EXERCISE-(JEE-MAIN)

$$1. \quad \Delta x \cdot \Delta v = \frac{h}{4\pi m} \Delta x = \frac{6.6 \times 10^{-34}}{4 \times 3.14 \times 9.218 \times 10^{-6}} = 2.86 \times 10^{-28} \text{ m}$$

$$2. \quad 2^{\text{nd}} \text{ excited state will be the } 3^{\text{rd}} \text{ energy level.} \quad E_n = \frac{13.6}{n^2} \text{ eV or } E = \frac{13.6}{9} = 1.51 \text{ eV.}$$

$$3. \quad \Delta x \cdot \Delta v = \frac{h}{4\pi m} \quad \Delta v = \frac{6.6 \times 10^{-34}}{4 \times 3.14 \times 25 \times 10^{-5}} \quad \therefore \Delta v = 2.1 \times 10^{-28} \text{ ms}^{-1}.$$

4. The value of ℓ (azimuthal quantum number) for s-electron is equal to zero.

$$\text{Orbital angular momentum} = \sqrt{\ell(\ell+1)} \cdot \frac{h}{2\pi}$$

$$\text{Substituting the value of } \ell \text{ for s-electron} = \sqrt{0(0+1)} \cdot \frac{h}{2\pi} = 0$$

$$5. \quad {}_{26}\text{Fe} = 1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^6, 4s^2,$$

$$\text{Fe}^{++} = 1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^6$$

The number of d-electrons retained in $\text{Fe}^{2+} = 6$.

$$6. \quad \lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34} \times 1000}{60 \times 10} = 11.05 \times 10^{-34} = 1.105 \times 10^{-33} \text{ metres.}$$

7. The electron has minimum energy in the first orbit and its energy increases as n increases. Here n represents number of orbit, i.e., 1st, 2nd, 3rd.....The third line from the red end corresponds to yellow region i.e., 5. In order to obtain less energy electron tends to come 1st or 2nd orbit. So jump may be involved either $5 \rightarrow 1$ or $5 \rightarrow 2$.

8. For 4 f orbital electrons, $n = 4$

$$\ell = 3, \quad m = +3, +2, +1, 0, -1, -2, -3 \quad s = +1/2.$$

$$9. \quad \frac{1}{\lambda} = R \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right); \quad \frac{1}{\lambda} = 1.097 \times 10^7 \left(\frac{1}{1^2} - \frac{1}{\infty^2} \right) \text{ m}^{-1} \quad \therefore \quad \lambda = 91 \times 10^{-9} \text{ m} = 91 \text{ nm.}$$

10. For hydrogen the energy order of orbital is $1s < 2s = 2p < 3s = 3p = 3d < 4s = 4p = 4d = 4f$.

11. Angular momentum of the electron, $mvr = \frac{nh}{2\pi}$ where $n = 5$ (given)

$$\therefore \text{Angular momentum} = \frac{5h}{2\pi} = 2.5 \frac{h}{\pi}$$

12. According to Heisenberg's uncertainty principle

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

$$\Delta x \times (m \cdot \Delta v) = \frac{h}{4\pi}; \quad \Delta x = \frac{h}{4\pi m \cdot \Delta v}$$

$$\Delta v = \frac{0.001}{100} \times 300 = 3 \times 10^{-3} \text{ ms}^{-1}$$

$$\therefore \Delta x = \frac{6.63 \times 10^{-34}}{4 \times 3.14 \times 9.1 \times 10^{-31} \times 3 \times 10^{-3}} = 1.92 \times 10^{-2} \text{ m.}$$

13. I.E. = $1.312 \times 10^6 \text{ J mol}^{-1}$

The energy required to excite the electron in the atom from $n_1 = 1$ to $n = 2$.

$$= 1.312 \times 10^6 \left[1 - \frac{1}{4} \right] = 9.84 \times 10^5 \text{ J mol}^{-1}$$

14. $\Delta v = \frac{0.005}{100} \times 600 = 3 \times 10^{-3} \text{ ms}^{-1}$

$$\Delta x = \frac{6.63 \times 10^{-34}}{4 \times 3.14 \times 9.1 \times 10^{-31} \times 3 \times 10^{-3}} = 1.92 \times 10^{-2} \text{ m.}$$

15. $\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{1.67 \times 10^{-27} \times 1000} = 3.97 \times 10^{-10} = 0.397 \text{ nm.}$

16. $\text{Cl-Cl(g)} \longrightarrow 2\text{Cl(g)}; \quad \Delta H = 242 \text{ KJ mol} = \frac{242 \times 10^3}{6.02 \times 10^{23}} \text{ J molecule}^{-1}$

$$E = \frac{hc}{\lambda} = \frac{242 \times 10^{-23} \times 10^3}{6.02} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{\lambda}$$

$$\lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{242 \times 10^{-23} \times 10^3} = \frac{6.6 \times 3 \times 6.02}{242} \times 10^{-6} = 0.494 \times 10^{-6} = 494 \times 10^{-9} \text{ m} = 494 \text{ nm}$$

17. I.E. of $\text{He}^+ = 19.6 \times 10^{-18} \text{ J atom}^{-1}$

$$\text{I.E.} = -E_1$$

$$E_1 \text{ for } \text{He}^+ \text{ is } = -19.6 \times 10^{-18} \text{ J atom}^{-1}$$

$$\frac{(E_1)_{\text{He}^+}}{(E_1)_{\text{Li}^{3+}}} = \frac{(Z_{\text{He}^+})^2}{(Z_{\text{Li}^{2+}})^2}$$

$$\frac{-19.6 \times 10^{-18}}{(E_1)_{\text{Li}^{2+}}} = \frac{4}{9}$$

$$E_1(\text{Li}^{2+}) = \frac{-19.6 \times 9 \times 10^{-18}}{4} = -44.1 \times 10^{-18} = -4.41 \times 10^{-17} \text{ J atom}^{-1}$$

18. $E = E_1 + E_2$

$$\frac{hc}{\lambda} = \frac{hc}{\lambda_1} + \frac{hc}{\lambda_2}; \quad \frac{1}{\lambda} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}; \quad \frac{1}{355} = \frac{1}{680} + \frac{1}{\lambda_2}$$

$$\lambda_2 = 742.76 \text{ nm.}$$

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

$$\nu_{\text{He}^+} = \nu_{\text{H}} \times z^2 \left(\frac{1}{\left(\frac{n_1}{2}\right)^2} - \frac{1}{\left(\frac{n_2}{2}\right)^2} \right) = \nu_{\text{H}} \left(\frac{1}{\left(\frac{2}{2}\right)^2} - \frac{1}{\left(\frac{4}{2}\right)^2} \right)$$

For H-atom

$$n_1 = 1, n_2 = 2$$

20. (a) 4 p (b) 4 s (c) 3 d (d) 3 p

Acc. to $(n + l)$ rule, increasing order of energy $(d) < (b) < (c) < (a)$

21. $\lambda = \frac{h}{\sqrt{2mKE}}$

22. $2\pi r = n\lambda; \quad 2\pi(9a_0) = 3\lambda$

$$\lambda = 6\pi a_0$$

23. $\frac{1}{\lambda} = R \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right); \quad \frac{1}{\lambda} = R \left(\frac{1}{2^2} - \frac{1}{3^2} \right) = \frac{5}{36} R$

$$24. \quad \lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{1000 \times 36 \times 1000}$$

25. For macro particles (having larger mass) will be most difficult to experimentally verify the de-Broglie relationship.

$$26. \quad \Delta E = \frac{13.6 Z^2}{n^2} = \frac{13.6 \times 9}{4} = 30.6 \text{ eV}$$

$$27. \quad E = -2.0 \times 10^{-18} \text{ J} \left(\frac{1}{4} - \frac{1}{1} \right) = 1.5 \times 10^{-18} \text{ J} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{\lambda}$$

$$\lambda = 1.325 \times 10^{-7} \text{ m}$$

$$28. \quad KE = E_p - W$$

$$\frac{1}{2} mv^2 = \frac{hc}{\lambda_0} - \frac{hc}{\lambda}; \quad v = \sqrt{\frac{2hc}{m} \left(\frac{\lambda_0 - \lambda}{\lambda \lambda_0} \right)}$$

$$(4) \sqrt{\frac{2hc}{m} (\lambda_0 - \lambda)}$$

$$29. \quad E = \frac{495.5 \times 10^3}{6.023 \times 10^{23}} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{\lambda}$$

$$30. \quad (E_n)_H = -13.6 \times \frac{1^2}{n^2} \text{ eV}$$

$$n = 2 \Rightarrow E_2 = -3.4 \text{ eV}$$

$$31. \quad K.E = \frac{3}{2} KT = \frac{1}{2} mv^2$$

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

$$\lambda = \frac{h}{\sqrt{2mK.E}}$$

$$\lambda = \frac{h}{\sqrt{2m} \times \frac{3}{2} KT}$$

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

$$32. \quad r = \frac{n^2 h^2}{4\pi^2 m e^2 k}$$

$$r = \frac{2^2 (6.6262 \times 10^{-34} \text{ Js})^2}{4 \times (3.1416)^2 \times 9.1091 \times 10^{-31} \text{ kg} \times (1.60210 \times 10^{-19} \text{ C})^2 \times 9 \times 10^9}$$

$$r = 2.12 \times 10^{-10} \text{ m}$$

$$r = 2.12 \text{ \AA}$$

$$33. \quad \bar{\nu} = R_H Z^2 \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

$$= R_H \times 1^2 \times \left(\frac{1}{n_f^2} - \frac{1}{8^2} \right)$$

$$\bar{\nu} = R_H \times \frac{1}{n_f^2} - R_H \times \frac{1}{8^2}$$

curve of $\bar{\nu}$ vs $\frac{1}{n^2}$ is linear

with slope = R_H

34. An electron in an orbital of high angular momentum stays away from the nucleus than an electron in the orbital of lower angular momentum since angular momentum(L) $\propto n$.

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

35. \div Graph (2) is wrong

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

$$Y = mX + C$$

Because this graph have a negative intercept.

$$36. \quad E_T = -13.6 \frac{Z^2}{n^2} \frac{\text{ev}}{\text{atom}}$$

For He^+

$$E_T = -13.6 \times \frac{2^2}{3^2} = -6.04 \text{ ev}$$

37. Energy of wave = $\frac{124}{\lambda(\text{nm})} \text{ eV} = \frac{1240}{900} \text{ eV} = 1.37 \text{ eV}$

This wave belong to paschen series of atomic spectra

for paschen series

$$\Delta E = 13.6 \times \frac{1}{9} = 1.51 \text{ eV}$$

So transition should be $\infty \rightarrow 3$

38. $h\nu = h\nu_0 + \text{K.E.} \dots (1)$

$$\text{K.E.} = \frac{h^2}{2m\lambda^2} \dots (2)$$

Putting (2) in (1)

$$\Rightarrow h\nu = h\nu_0 + \frac{h^2}{2m\lambda^2} \Rightarrow h(\nu - \nu_0) = \frac{h^2}{2m\lambda^2}$$

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

39. $\frac{hc}{\lambda} = kE + W_0$

$$kE = \frac{1}{2} \times 9 \times 10^{-31} \times 36 \times 10^{10}$$

$$= 162 \times 10^{-21} \text{ J} = \frac{162 \times 10^{-21}}{1.6 \times 10^{-19}} = 1 \text{ eV}$$

$$\text{Energy of incident light} = \frac{12400}{4000} \text{ eV} = 3.1 \text{ eV}$$

$$\Rightarrow W_0 = 3.1 - 1 = 2.1 \text{ eV}$$

40. $\because 2\pi r_n = n\lambda \text{ \& } r_n = r_0 \times \frac{n^2}{Z}$

$$\therefore 2\pi \left(r_0 \times \frac{n^2}{Z} \right) = n (1.5\pi r_0)$$

$$\frac{n}{2} = \frac{1.5}{2} = 0.75$$

41. (I) $n = 4 \quad l = 2 \quad m_l = -2 \quad m_s = -1/2$

represents e^- present in 4d orbital

(II) $n = 3 \quad l = 2 \quad m_l = 1 \quad m_s = +1/2$

represents e^- present in 3d orbital

(IV) $n = 4 \quad l = 1 \quad m_l = 0 \quad m_s = +1/2$

represents e^- present in 4p orbital

(V) $n = 3 \quad l = 1 \quad m_l = 1 \quad m_s = -1/2$

represents e^- present in 3p orbital

According to $(n+l)$ rule, order of energy will be

$$3p < 3d < 4p < 4d$$

42. $K \cdot E = h\nu - w_0$

$$\therefore K.E \gg w_0$$

$$\therefore h\nu \gg w_0$$

$$\therefore K.E = h\nu = \frac{hc}{\lambda}$$

$$K \cdot E \propto \frac{1}{\lambda}$$

$$\therefore K \cdot E = \frac{p^2}{2m}$$

$$\therefore p^2 \propto \frac{1}{\lambda}$$

$$\therefore \frac{\lambda_2}{\lambda_1} = \left(\frac{p_1}{p_2} \right)^2 = \left(\frac{p_1}{1.5p_1} \right)^2 \Rightarrow \lambda_2 = \frac{4}{9} \lambda_1$$

43. For Lyman series maximum frequency of photon will be observed when electron makes transition from $n = \infty$ to $n = 1$ and a photon of minimum frequency will be observed when makes transition from $n = 2$ to $n = 1$

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

$$\Delta \bar{\nu}_{\text{Lyman}} = R_C Z^2 \left[\frac{1}{1} - \frac{1}{\infty} \right] - R_C Z^2 \left[\frac{1}{1} - \frac{1}{4} \right] = R_C Z^2 - \frac{3R_C Z^2}{4} = \frac{R_C Z^2}{4}$$

For Balmer series

Maximum frequency $n = \infty$ to $n = 2$

Maximum frequency $n = 3$ to $n = 2$

$$\Delta \bar{\nu}_{\text{Balmer}} = R_C Z^2 \left[\frac{1}{2^2} - \frac{1}{\infty} \right] - R_C Z^2 \left[\frac{1}{2^2} - \frac{1}{3^2} \right] = \frac{R_C Z^2}{4} - \frac{5R_C Z^2}{36} = \frac{R_C Z^2}{9}$$

$$\frac{\Delta \bar{\nu}_{\text{Lyman}}}{\Delta \bar{\nu}_{\text{Balmer}}} = \frac{\frac{R_C Z^2}{4}}{\frac{R_C Z^2}{9}} = \frac{9}{4}$$

44. Total energy of electron will be maximum at $n = \infty$

45. There is only one radial node and probability of finding the electrons is maximum near nucleus, graph belongs to 2s orbital.

46. For Lyman series

$$\frac{1}{\lambda_{\max}} = R_H Z^2 \times \left(\frac{1}{1^2} - \frac{1}{\infty^2} \right)$$

$$\frac{1}{\lambda_{\max}} = R_H Z^2$$

$$\text{For Paschen series} = \frac{1}{\lambda_{\max}} = R_H Z^2 \left(\frac{1}{3^2} - \frac{1}{\infty^2} \right)$$

$$\frac{1}{\lambda_{\max}} = R_H Z^2 \times \frac{1}{9}$$

$$(\lambda_{\max})_{\text{paschen}} = \frac{1}{9}$$

$$(\lambda_{\max})_{\text{Lyman}} = 1$$

$$\frac{(\lambda_{\max})_{\text{Paschen}}}{(\lambda_{\max})_{\text{Lyman}}} = \frac{9}{1}$$

47. We are getting maxima at point a & c

Electrons are more likely to be found in the region a & c.

48. Internal energy of Ar will be equal to KE of Ar and KE is explained by KTG.

$$49. \quad r = a_0 \times \frac{n^2}{Z}$$

for second orbit of Li^{2+}

$$r = a_0 \times \frac{4}{3} = \frac{4a_0}{3}$$

50. For Balmer series $n_1 = 2$ $n_2 = 3, 4, 5, \dots$

For Balmer series, Energy of 1st line ($3 \rightarrow 2$) is minimum so λ will be max
lines in series converge, Energy is increased so λ is decreased.

51. $E = W + KE_{\max}$

$$KE_{\max} = E - W$$

$$= \frac{hc}{\lambda} - 4.41 \times 10^{-19}$$

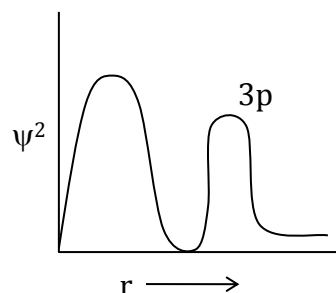
$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{300 \times 10^{-9}} - 4.41 \times 10^{-19}$$

$$= 2.22 \times 10^{-19} \text{ J}$$

$$= 222 \times 10^{-21} \text{ J}$$

52. Probability density = ψ^2

ψ^2 can be zero for 3p orbital besides of infinite distance



54. Total energy per sec. = 50 J

$$50 = \frac{n \times 6.63 \times 10^{-34} \times 3 \times 10^8}{795 \times 10^{-9}}$$

$$n = 1998.49 \times 10^{17} \text{ [n = no. of photons per second]}$$

$$= 1.998 \times 10^{20}$$

$$\approx 2 \times 10^{20}$$

$$= x \times 10^{20}$$

$$x = 2$$

58. $v_e = x v_N$

$$\lambda_e = \lambda_N$$

$$\Rightarrow \frac{h}{m_e v_e} = \frac{h}{m_N v_N}$$

$$v_e = \frac{m_N}{m_e} \cdot v_N$$

$$= \frac{1.6 \times 10^{-27}}{9.1 \times 10^{-31}} v_N$$

$$v_e = 1758.24 \times v_N$$

$$\therefore x = 1758.24$$

59. Heisenberg's uncertainty principle

$$\Delta x \times \Delta p_x \geq \frac{h}{4\pi}$$

$$\Rightarrow 2a_0 \times m\Delta v_x = \frac{h}{4\pi} \text{ (minimum)}$$

$$\Rightarrow \Delta v_x = \frac{h}{4\pi} \times \frac{1}{2a_0} \times \frac{1}{m}$$

$$= \frac{6.63 \times 10^{-34}}{4 \times 3.14 \times 2 \times 52.9 \times 10^{-12} \times 9.1 \times 10^{-31}}$$

$$= 548273 \text{ ms}^{-1}$$

$$= 548.273 \text{ km s}^{-1}$$

$$= 548 \text{ km s}^{-1}$$

60. Atomic orbital is characterised by n , l , m .
61. For 2s, number of radial nodes = $2 - 0 - 1 = 1$ and value of ψ^2 is always positive.
62. (A) Number of values of $n = 1, 2, 3 \dots \infty$
 (B) Number of values of $l = 0$ to $(n - 1)$
 (C) Number of values of $m = -l$ to $+l$
 Total values = $2l + 1$
 (D) Values of spin = $\pm \frac{1}{2}$
 (E) For $l = 5$ number of orbitals = $2l + 1 = 11$

EXERCISE # (JEE-ADVANCE)

- The quantum numbers $+1/2$ and $-1/2$ for the electron spin represent two quantum mechanical spin states which have no classical analogue.
- α - particles are He nuclei.
- Cobalt is present as Co^{+2} which has $[\text{Ar}] 4s^0 3d^7$ configuration, which means it has 3 unpaired electrons. So the spin only magnetic moment of the compound is $\sqrt{3(3+2)} = \sqrt{15}$

$$4. \quad r_n = 0.529 \frac{n^2}{Z} \text{ \AA}$$

For hydrogen, $n = 1$ and $Z = 1$; $\therefore r_H = 0.529 \text{ \AA}$

For Be^{3+} , $n = 2$ and $Z = 4$; $\therefore r_{\text{Be}^{3+}} = \frac{0.529 \times 2^2}{4} = 0.529 \text{ \AA}$

- ψ^2_{2s} = probability of finding electron with in 2s orbital
 $\psi^2_{\text{at node}} = 0$ (probability of finding an electron is zero at node)
 For node at $r = r_0$, $\psi^2 = 0$

$$\text{So, } \psi^2 = 0 = \frac{1}{4\sqrt{2}\pi} \left[\frac{1}{a_0} \right]^3 \left[2 - \frac{r_0}{a_0} \right] \times e^{-r_0/2a_0}$$

$$\Rightarrow \left[2 - \frac{r_0}{a_0} \right] = 0 \text{ or } 2 = \frac{r}{a_0}$$

$$\Rightarrow r = 2a_0$$

$$(b) \quad \lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}}{100 \times 100 \times 10^{-3}} = \frac{6.626 \times 10^{-34}}{10,000 \times 10^{-3}} = 6.626 \times 10^{-35} \text{ m or } 6.626 \times 10^{-25} \text{ \AA}$$

- For hydrogen atom, $Z = 1$, $n = 1$

$$v = 2.18 \times 10^6 \times \frac{Z}{n} \text{ ms}^{-1} = 2.18 \times 10^6 \text{ ms}^{-1}$$

$$(b) \quad \text{de Broglie wavelength, } \lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}}{9.1 \times 10^{-31} \times 2.18 \times 10^6} = 3.32 \times 10^{-10} \text{ m} = 3.3 \text{ \AA}$$

- For 2p, $l = 1$

$$\therefore \text{Orbital angular momentum} = \sqrt{\ell(\ell+1)} \frac{h}{2\pi} = \sqrt{2} \frac{h}{2\pi} ..$$

$$7. \left. \begin{aligned} K_n &= \frac{KZe^2}{2r} \\ V_n &= -\frac{KZe^2}{r} \\ E_n &= -\frac{KZe^2}{2r} \end{aligned} \right\} \text{ so, } \frac{V_n}{K_n} = -2 \text{ and } E_n \propto \frac{1}{r}.$$

8. Magnetic moment of orbital angular momentum of the electron in a hydrogen-like atomic orbital depends on azimuthal quantum number and its direction depends on magnetic quantum number

9. For lower state (S_1)

$$\text{Number of radial node} = 1 = n - l - 1$$

Put $n = 2$ and $l = 0$ (as higher state S_2 has $n = 3$)

So, it would be $2s$ (for S_1 state)

$$10. \text{ Energy of state } S_1 = -13.6 \left(\frac{3^2}{2^2} \right) \text{ eV/atom}$$

$$= \left(\frac{3^2}{2^2} \right) (\text{energy of H-atom in ground state})$$

$$= 2.25 (\text{energy of H-atom in ground state}).$$

11. For state S_2

$$\text{Number of radial node} = 1 = n - l - 1 \quad \dots\dots (\text{eq.-1})$$

Energy of S_2 state = energy of e^- in lowest state of H-atom

$$= -13.6 \text{ eV/atom} = -13.6 \left(\frac{3^2}{n^2} \right) \text{ eV/atom ; } n = 3.$$

Put in equation (1) $l = 1$ so, orbital is $3p$ (for S_2 state).

12. Electrons with spin quantum number $= -\frac{1}{2}$ will be 1(in s) + 3(in p) + 5(in d) = 9.

$$13. E_{\text{photon}} = \frac{12400}{3000} = 4.13 \text{ eV}$$

Photoelectric effect can take place only if $E_{\text{photon}} \geq \phi$

Thus,

Li, Na, K, Mg can show photoelectric effect.

14. $mv(4a_0) = \frac{h}{\pi}$

so, $v = \frac{h}{4m\pi a_0}$

so, $KE = \frac{1}{2} mv^2 = \frac{1}{2} m \cdot \frac{h^2}{16m^2\pi^2 a_0^2} = \frac{h^2}{32m\pi^2 a_0^2}$

15. $\lambda = \frac{h}{\sqrt{2m(KE)}} \quad KE \propto T$

$\frac{\lambda_{He}}{\lambda_{Ne}} = \sqrt{\frac{m_{Ne} KE_{Ne}}{m_{He} KE_{He}}} = \sqrt{\frac{20 \times 1000}{4 \times 200}} = 5.$

16. $n = 4, \quad m_l = 1, -1$

Hence l can be $= 3, 2, 1$

i.e. H_f ; 2 orbitals

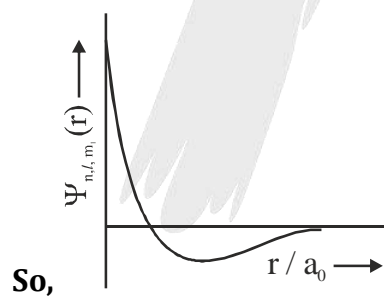
H_d ; 2 orbitals

H_p ; 2 orbitals

Hence total of 6 orbitals, and we want $m_s = -\frac{1}{2}$, that is only one kind of spin. So, 6 electrons.

17. 1s orbital does not have any spherical node.

18. Number of radial nodes in 2s orbital $= n - \ell - 1 = 1$



19. 1s orbital cannot have angular part of wave function so, (D) is incorrect.

20. For H - atom $\Psi_{n,l,m_l} \propto \left(\frac{Z}{a_0}\right)^{\frac{3}{2}} e^{-\left(\frac{Zr}{a_0}\right)}$

$$\frac{E_4 - E_2}{E_6 - E_2} = \frac{13.6 \times \left[\frac{1}{4} - \frac{1}{9} \right]}{13.6 \times \left[\frac{1}{4} - \frac{1}{36} \right]} = \frac{27}{32}$$

21. $E = E_0 \frac{z^2}{n^2}$

$$3.4 = 13.6 \times 4/n^2$$

$$n = 2$$

$$l = 2$$

(a) Subshell is 4 d

(b) Number of angular nodes is 2

(c) Number of radial nodes is 1 .

(d) Nuclear charge would be the same.

22. Total energy = $-13.6 \times \frac{z^2}{n^2} \text{ eV}$

$$-3.4 \text{ eV} = -13.6 \times \frac{2^2}{n^2} \text{ eV}$$

$$n^2 = \frac{13.6}{3.4} \times 2^2 = 16; \quad n = 4$$

Value of $\ell = 2$, So, it's a 4d orbital.

Number of angular nodes = $\ell = 2$

Number of radial nodes = $n - \ell - 1 = 4 - 2 - 1 = 1$

Effective nuclear charge at this electron will be equal to 2e since no shielding effect.

23. (1) Radius of the n^{th} orbit $\propto n^2$

(2) Angular momentum of the electron in the n^{th} orbit $\propto n$

(3) Kinetic energy of the electron in the n^{th} orbit $\propto \frac{1}{n^2}$

(4) Potential energy of the electron in the n^{th} orbit $\propto \frac{1}{n^2}$

24. P. E of 2H-atoms

Total eng = P.E. / 2

Potential Energy = 2 Total Energy

$$E = -13.6 \times z^2/n^2 \text{ eV/atom}$$

$$= -2 \times 13.6 \times z^2/n^2 \text{ eV/atom} + (-2 \times 13.6 \times z^2/n^2) \text{ eV/atom}$$

$$= -2 \times 2 \times 13.6 \times 1 \times \text{ev/atom}$$

$$= -4 \times 13.6 \times 1.6 \times 10^{-19} \text{ J/atom} \times 6.023 \times 10^{23} \text{ atom/mole}$$

$$= -4 \times 13.6 \times 1.6 \times 6.023 \times 10^4 \text{ J/mole}$$

$$= -5242.42 \text{ KJ/mol}$$

25. Momentum of photon $= \frac{h}{\lambda} = \frac{6.6 \times 10^{-27}}{330 \times 10^{-7}}$

gmcms

Momentum of 1 mole of He-atoms $= m\Delta v$

$$\therefore m\Delta v = N_A \times h/\lambda$$

$$4 \times \Delta v = \frac{6 \times 10^{23} \times 6.6 \times 10^{-27}}{330 \times 10^{-7}}$$

$$\Delta v = \frac{6 \times 6.6 \times 10^2}{33 \times 4} = 30 \text{ cm s}^{-1}$$

$$\therefore \text{Change in velocity of He-atoms} = 30 \text{ cm s}^{-1}$$

26. $r = 52.9 \times \frac{n^2}{z} \text{ pm}$

$$\therefore 105.8 = \frac{52.9 \times n^2}{2} \therefore n_2 = 2$$

$$\text{and } 26.45 = 52.9 \times \frac{n^2}{2} \therefore n_1 = 1$$

$$\Delta E = R_H hC \times z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$$

$$\frac{hc}{\lambda} = R_H hC \times z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{\lambda} = 2.2 \times 10^{-18} \times 4 \times \left[\frac{1}{1} - \frac{1}{4} \right]$$

$$\frac{6.6 \times 10^{-34} \times 3 \times 10^8}{\lambda} = 2.2 \times 10^{-18} \times 4 \times \frac{3}{4}$$

$$\therefore \lambda = 300 \text{ \AA}$$

$$\therefore \lambda = 30 \text{ nm}$$