ATOMIC STRUCTURE

1. INTRODUCTION :

The existence of atoms has been proposed since the time of early Indian and Greek philosophers (400 B.C.) who were of the view that atoms are the fundamental building blocks of matter. According to them, the continued subdivisions of matter would ultimately yield atoms which would not be further divisible. The word 'atom' has been derived from the Greek word 'a-tomio' which means 'uncuttable' or 'non-divisible'. These earlier ideas were mere speculations and there was no way to test them experimentally. These ideas remained dormant for a very long time and were revived again by scientists in the nineteenth century. 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.

2. DALTON ATOMIC THEORY :

(i) Atom is the smallest particle of any substance which cannot be divided further.

(ii) Atoms can never be created nor be destroyed. Only the rearrangement of atoms occurs in chemical reactions.

(iii) All the atoms are hard and dense.

(iv) All the atoms of an element are identical but the atoms of different elements will be different.

(v) A compound is formed by the combinations of atoms of different elements in a fixed ratio by mass.

We start with the experimental observations made by scientists towards the end of nineteenth and beginning of twentieth century. These established that atoms can be further divided into subatomic particles, i.e., electrons, protons and neutrons. a concept very different from that of Dalton. The major problems before the scientists at that time were:

- to account for the stability of atom after the discovery of sub-atomic particles,
- to compare the behaviour of one element from other in terms of both physical and chemical properties,
- to explain the formation of different kinds of molecules by the combination of different atoms and,
- to understand the origin and nature of the characteristics of electromagnetic radiation absorbed or emitted by atoms.

3. SUB-ATOMIC PARTICLES

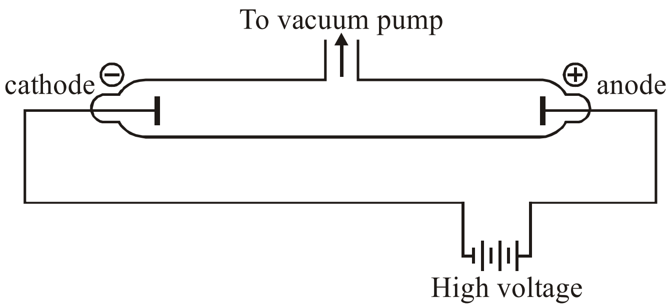
Dalton's atomic theory was able to explain the law of conservation of mass, law of constant composition and law of multiple proportion very successfully. However, it failed to explain the results of many experiments, for example, it was known that substances like glass or ebonite when rubbed with silk or fur generate electricity. Many different kinds of sub-atomic particles were discovered in the twentieth century.

3.1 Discovery of Electron :

In 1830, Michael Faraday showed that if electricity is passed through a solution of an electrolyte, chemical reactions occurred at the electrodes, which resulted in the liberation and deposition of matter at the electrodes. These results suggested the particulate nature of electricity.

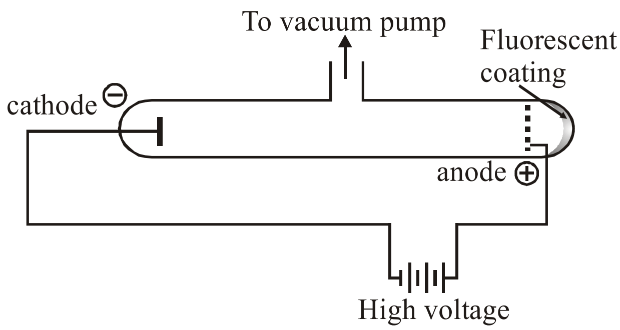
An insight into the structure of atom was obtained from the experiments on electrical discharge through gases. Before we discuss these results we need to keep in mind a basic rule regarding the behaviour of charged particles: "Like charges repel each other and unlike charges attract each other".

In mid 1850s many scientists mainly Faraday began to study electrical discharge in partially evacuated tubes, known as **cathode ray discharge tubes**.



A cathode ray discharge tube

A cathode ray tube is made of glass containing two thin pieces of metal, called electrodes, sealed in it. The electrical discharge through the gases could be observed only at very low pressures and at very high voltages. The pressure of different gases could be adjusted by evacuation. When sufficiently high voltage is applied across the electrodes, current starts flowing through a stream of particles moving in the tube from the negative electrode (cathode) to the positive electrode (anode). These were called **cathode rays or cathode ray particles**. The flow of current from cathode to anode was further checked by making a hole in the anode and coating the tube behind anode with phosphorescent material zinc sulphide. When these rays, after passing through anode, strike the zinc sulphide coating, a bright spot on the coating is developed(same thing happens in a television set)



A cathode ray discharge tube with perforated anode

The results of these experiments are summarised below.

(i) The cathode rays start from cathode and move towards the anode.

(ii) These rays themselves are not visible but their behaviour can be observed with the help of certain kind of materials (fluorescent or phosphorescent) which glow when hit by them. Television picture tubes are cathode ray tubes and television pictures result due to fluorescence on the television screen coated with certain fluorescent or phosphorescent materials.

(iii) In the absence of electrical or magnetic field, these rays travel in straight lines.

(iv) In the presence of electrical or magnetic field, the behaviour of cathode rays are similar to that expected from negatively charged particles, suggesting that the cathode rays consist of negatively charged particles, called **electrons**.

(v) The characteristics of cathode rays (electrons) do not depend upon the material of electrodes and the nature of the gas present in the cathode ray tube.

Thus, we can conclude that electrons are basic constituent of all the atoms.

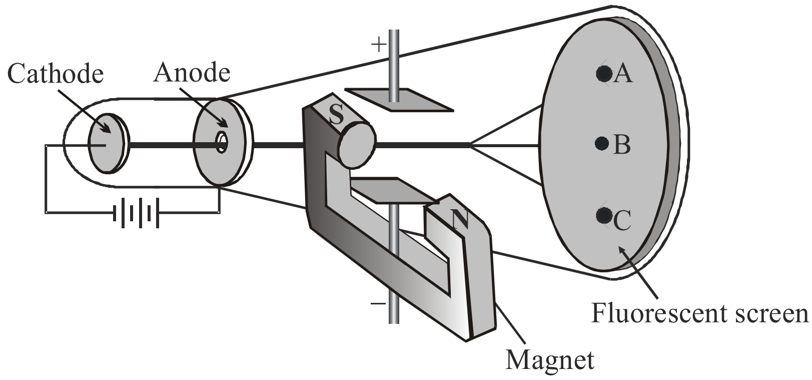
3.1.1 Charge to Mass Ratio of Electron :

In 1897, British physicist J.J. Thomson measured the ratio of electrical charge (e) to the mass of electron (m_e) by using cathode ray tube and applying electrical and magnetic field perpendicular to each other as well as to the path of electrons. Thomson argued that the amount of deviation of the particles from their path in the presence of electrical or magnetic field depends upon :

(i) the magnitude of the negative charge on the particle, greater the magnitude of the charge on the particle, greater is the interaction with the electric or magnetic field and thus greater is the deflection.

(ii) the mass of the particle lighter the particle, greater the deflection.

(iii) the strength of the electrical or magnetic field . the deflection of electrons from its original path increases with the increase in the voltage across the electrodes, or the strength of the magnetic field.



The apparatus to determine the charge to the mass ratio of electron

When only electric field is applied, the electrons deviate from their path and hit the cathode ray tube at point A. Similarly when only magnetic field is applied, electron strikes the cathode ray tube at point C. By carefully balancing the electrical and magnetic field strength, it is possible to bring back the electron to the path followed as in the absence of electric or magnetic field and they hit the screen at point B. By carrying out accurate measurements on the amount of deflections observed by the electrons on the electric field strength or magnetic field strength, Thomson was able to determine the value of e/me as:

$$\frac{e}{m_e} = 1.758820 \times 10^{11} \, C\,kg^{-1}$$

where m_e is the mass of the electron in kg and e is the magnitude of the charge on the electron in coulomb (C). Since electrons are negatively charged, the charge on electron is –e.

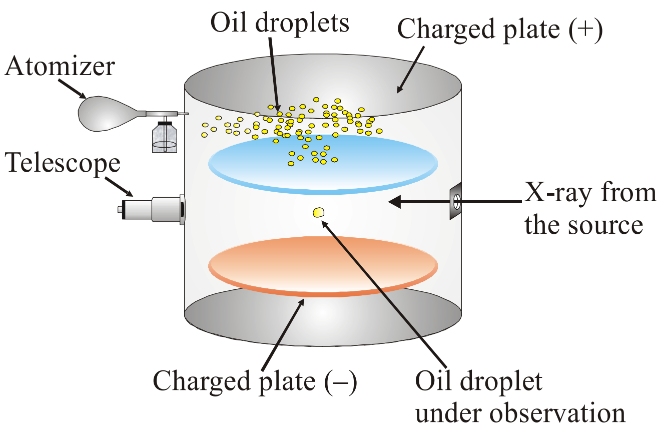
3.1.2 Charge on the Electron :

R.A. Millikan (1868-1953) devised a method known as oil drop experiment (1906-14), to determine the charge on the electrons. He found that the charge on the electron to be -1.6×10^{-19} C. The present accepted value of electrical charge is -1.6022×10^{-19} C. The mass of the electron (m_e) was determined by combining these results with Thomson's value of e/m ratio.

$$m_e = \frac{e}{e/m_e} = \frac{1.6022 \times 10^{-19} C}{1.758820 \times 10^{11} C\,kg^{-1}} = 9.1094 \times 10^{-31} kg$$

Millikan's Oil Drop Method

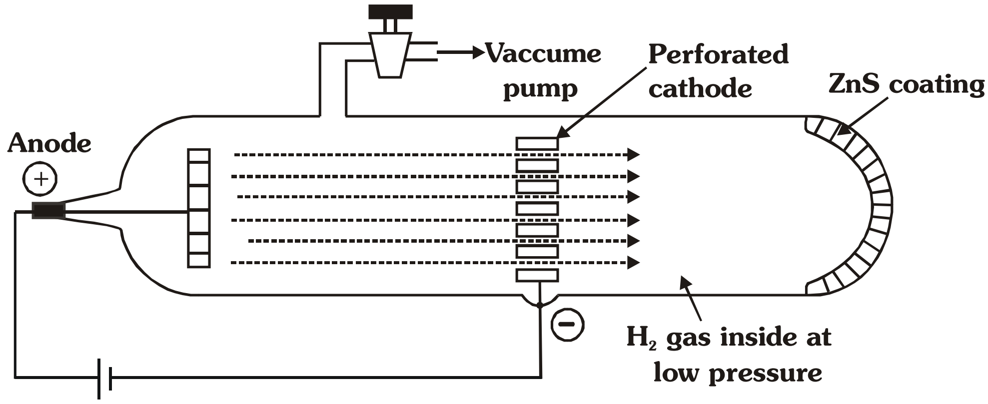
In this method, oil droplets in the form of mist, produced by the atomiser, were allowed to enter through a tiny hole in the upper plate of electrical condenser. The downward motion of these droplets was viewed through the telescope, equipped with a micrometer eye piece. By measuring the rate of fall of these droplets, Millikan was able to measure the mass of oil droplets.The air inside the chamber was ionized by passing a beam of X-rays through it. The electrical charge on these oil droplets was acquired by collisions with gaseous ions. The fall of these charged oil droplets can be retarded, accelerated or made stationary depending upon the charge on the droplets and the polarity and strength of the voltage applied to the plate. By carefully measuring the effects of electrical field strength on the motion of oil droplets, Millikan concluded that the magnitude of electrical charge, q, on the droplets is always an integral multiple of the electrical charge, e, that is, q = n e, where n = 1, 2, 3... . The highest common factor (HCF) of charges on oil droplet was taken as charge on electron.



The Millikan oil drop apparatus for measuring charge 'e'. In chamber, the forces acting on oil drop are: gravitational, electrostatic due to electrical field and a viscous drag force when the oil drop is moving.

3.2 CANAL RAYS (OR ANODE RAYS) – DISCOVERY OF PROTON :

Atoms are electrically neutral. Hence after the discovery of the negatively charged constituent (electron) of an atom, attempts were made to discover the positively charged counterpart of electrons. By using a discharge tube containing a perforated cathode, ***Goldstein (1886)*** found that some rays passed through these holes in a direction opposite to that of the cathode rays.



Positive Rays or Canal Rays

Electrical discharge carried out in the modified cathode ray tube led to the discovery of particles carrying positive charge, also known as **canal rays**. The characteristics of these positively charged particles are listed below.

(i) unlike cathode rays, the positively charged particles depend upon the nature of gas present in the cathode ray tube. These are simply the positively charged gaseous ions.

(ii) The charge to mass ratio of the particles is found to depend on the gas from which these originate.

(iii) Some of the positively charged particles carry a multiple of the fundamental unit of electrical charge.

(iv) The behaviour of these particles in the magnetic or electrical field is opposite to that observed for electron or cathode rays.

The smallest and lightest positive ion was obtained from hydrogen and was called proton. This positively charged particle was characterised in 1919.

The lightest positively charged particle is called a proton (P or P+). Positive rays are atomic or molecular cations from which some electrons have been removed. The removed electrons constitute the cathode rays and the positive cations form the positive or canal rays.

3.3 DISCOVERY OF NEUTRON :

After the discovery of electron and proton ***Rutherford (1920)*** predicted the existence of a neutral fundamental particle. In ***1932, Chadwick*** bombarded the element Beryllium with α-particles and noticed the emission of a radiation having the following characteristics.

(i) The radiation was highly penetrating.

(ii) The radiation was unaffected by magnetic and electric fields which shows that it is electrically neutral.

(iii) It was found to have approximately the same mass as the protons.

The name 'neutron' was given to this sub-atomic particle. It is denoted by n or ${}_0n^1$. Bombardment of beryllium by α-particles results in the formation of carbon and neutrons are emitted.

$${}_4Be^9 + {}_2He^4 \longrightarrow {}_6C^{12} + {}_0n^1$$

Mass of a neutron is 1.00867 amu (1.67493×10^{-24}g or 1.67493×10^{-27} kg)

3.4 PROPERTIES OF FUNDAMENTAL PARTICLES :

Atoms are made up-essentially, of three fundamental particles, which differ in mass and electric charge as follows :

	Electron	Proton	Neutron
Symbol	e or e^-	p	n
Approximate relative mass	1/1836	1	1
Approximate relative charge	–1	+1	0
Mass in kg	9.10939×10^{-31}	1.67262×10^{-27}	1.67493×10^{-27}
Mass in amu	0.00054	1.00727	1.00867
Actual charge/C	-1.6022×10^{-19}	$+1.6022 \times 10^{-19}$	0

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

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

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

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

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

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

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

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

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

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

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

Answer. b, e

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

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

$$(2\times1.6\times10^{-19}\times V)=\frac{1}{2}\times4\times1.66\times10^{-27}\times(5\times10^6)^2$$

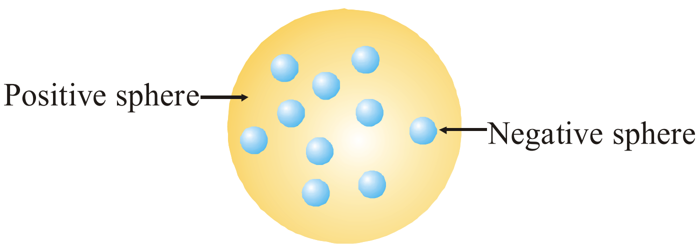
4. ATOMIC MODELS :

Observations obtained from the experiments mentioned in the previous sections have suggested that Dalton's indivisible atom is composed of sub-atomic particles carrying positive and negative charges. Different atomic models were proposed to explain the distributions of these charged particles in an atom. Although some of these models were not able to explain the stability of atoms, two of these models, proposed by J. J. Thomson and Ernest Rutherford are discussed below.

4.1 Thomson Model of Atom :

J. J. Thomson, in 1898, proposed that an atom possesses a spherical shape (radius approximately 10^{10} m) in which the positive charge is uniformly distributed. The electrons are embedded into it in such a manner as to give the most stable electrostatic arrangement. Many different names are given to this model, **for example, plum pudding, raisin pudding or watermelon**. This model can be visualised as a pudding or watermelon of positive charge with plums or seeds (electrons) embedded into it. An important feature of this model is that the mass of the atom is assumed to be uniformly distributed over the atom. Although this model was able to explain the overall neutrality of the atom, but was not consistent with the results of later experiments.

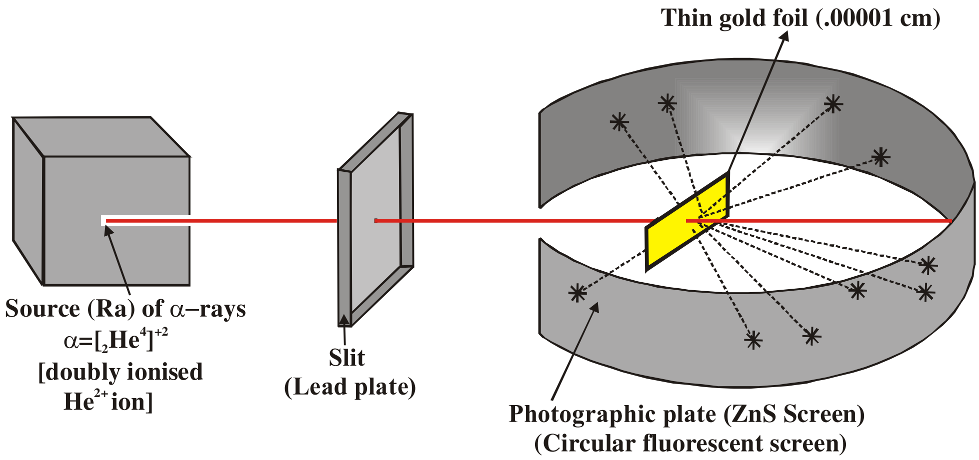
Thomson was awarded Nobel Prize for physics in 1906, for his theoretical and experimental investigations on the conduction of electricity by gases.

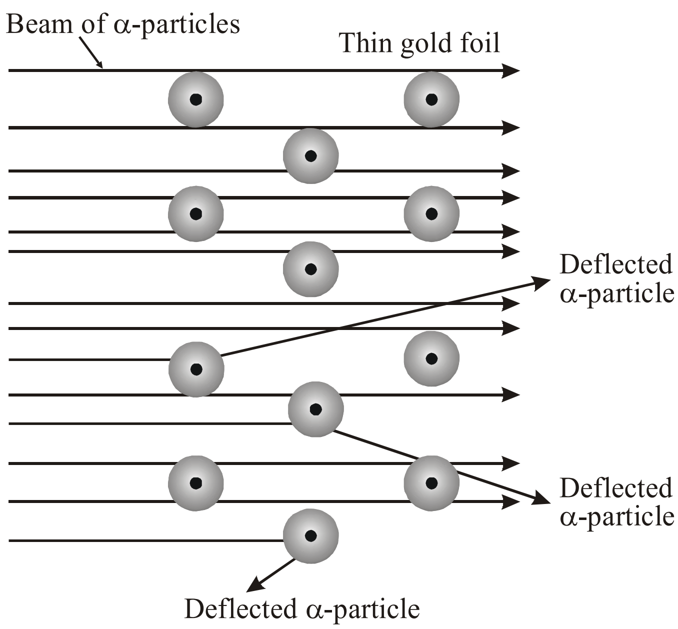


Thomson model of atom

4.2 Rutherford's model :

Rutherford's α-scattering experiment





B. Schematic molecular view of the gold foil

❖ Observations and conclusions :

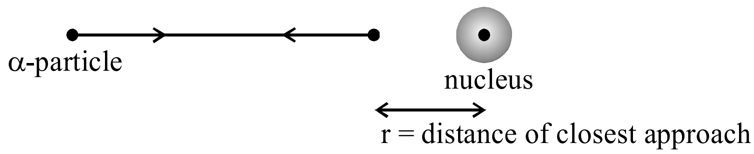
(i) Most of the α-particles passed through the gold foil undeflected. Hence, most of the space in the atom is empty.

(ii) A small fraction of α-particles was deflected by small angles. A very few α-particles (~1 in 20,000) bounced back, that is, were deflected by nearly 180°.

The deflection must be due to enormous repulsive force showing that the positive charge of the atom is not spread throughout the atom as Thomson had presumed. The positive charge has to be concentrated in a very small volume that repelled and deflected the positively charged α-particles. Rutherford given the name **nucleus** to this positively charged center of atom.

(iii) The volume occupied by the nucleus is negligibly small as compared to the total volume of atom. The radius of the atom is about 10^{-10} m, while that of nucleus is 10^{-15} m.

Rutherford estimated the size of nucleus by calculating the distance of closes approach.



The initial kinetic energy of α-particle must be equal to potential energy at distance of closest approach.

$$\text{K.E.} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1\cdot q_2}{r} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{(2e)\cdot(Ze)}{r}$$

$$\boxed{r = \frac{2Ze^2}{(4\pi\varepsilon_0)(\text{K.E.})}}$$

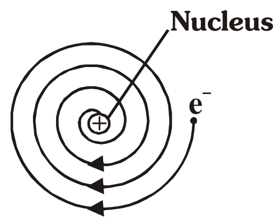
where Z = atomic number of element used in foil.

(iv) Almost all mass of the atom is densely concentrated in extremely small region (nucleus).

(v) The nucleus is surrounded by electrons that move around the nucleus with a very high speed in circular paths called orbits. Electrons and the nucleus are held together by electrostatic forces of attraction.

4.2.1 Drawbacks of Rutherford model :

(i) According to the electromagnetic theory of Maxwell, charged particles when accelerated should emit electromagnetic radiation Therefore, an electron in an orbit will emit radiation, the energy carried by radiation comes from electronic motion. The orbit will thus continue to shrink.



Calculations show that it should take an electron only 10^{-8} s to spiral into the nucleus. But this does not happen. Thus, the Rutherford model cannot explain the stability of an atom.

(ii) It does not explain the arrangement of electrons revolving round nucleus.

(iii) It does not explain the stability of nucleus against strong repulsive forces.

(iv) It does not explain atomic spectrum.

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

Sol : $K.E. = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1q_2}{r}$

or $5.4 \times 10^6 \times 1.6 \times 10^{-19} = 9 \times 10^9 \times \frac{(2\times1.6\times10^{-19})\times(79\times1.6\times10^{-19})}{r}$

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

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

(A) Na (Z = 11) ***(B) Ca (Z = 20)***

(C) Ag (Z = 47) ***(D) Au (Z = 79)***

Answer.(A)

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

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

Answer.(D)

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

K.E. = 7.7 M eV

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

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

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

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

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

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

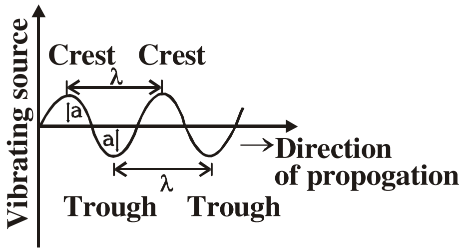
5. *WAVE THEORY :*

A wave is defined as a periodic disturbance in space or in a medium that involves elastic displacement of material particles or a periodic change in some physical quantities such as T, P, V etc. Thus, wave motion represents propagation of a periodic disturbance carrying energy. The wave travels at right angles to the vibratory motion of the object.

When an object moves up and down or vibrates continuously, energy in the form of waves is transmitted by a vibrating object to a distant place. For example , when a stone is thrown in a still water of a pond, a disturbance is produced at a place where the stone strikes the water.

This disturbance advances outwards in the same form and reaches the edges of the pond. Such a disturbance is called a ***mechanical wave***. The mechanical waves transmit only in a material medium. Besides the mechanical waves, there are waves which do not require any medium for their transmission. These waves are called ***electromagnetic waves*** or ***electromagnetic radiations.***

5.1 WAVE CHARACTERISTICS :



I. Wavelength (λ) :

It is defined as the distance between two nearest crests or nearest troughs.

It is measured in terms of a Å (Angstrom), pm (Picometre), nm (nanometer), cm(centimetre), m (metre)

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

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.

$c = \lambda / T = \lambda\nu$ $\quad$ $\nu = c/\lambda$ $\quad$ $c = \nu\ (sec^{-1}) \times \lambda\ (m)$ $\quad$ $c = \nu\lambda\ (m\ sec^{-1})$

Since c is constant for em-waves.

i.e. frequency is inversely propotional to λ

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

It is defined as number of waves per unit length. It is denoted by $\bar{\nu}$ & is expressed in cm^{-1}.

λ m $\rightarrow$ 1 wave

1 m $\rightarrow$ $1/\lambda$ waves

$$\bar{\nu} = \frac{1}{\lambda} \qquad (1\ cm^{-1} = 100\ m^{-1})$$

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

VI. Amplitude (a) :

It is the height of the crest or depth of the trough of a wave and is denoted by 'a'. It is half the vertical distance from the top of the wave to the bottom of the wave. It determines the intensity or brightness of the beam of light.

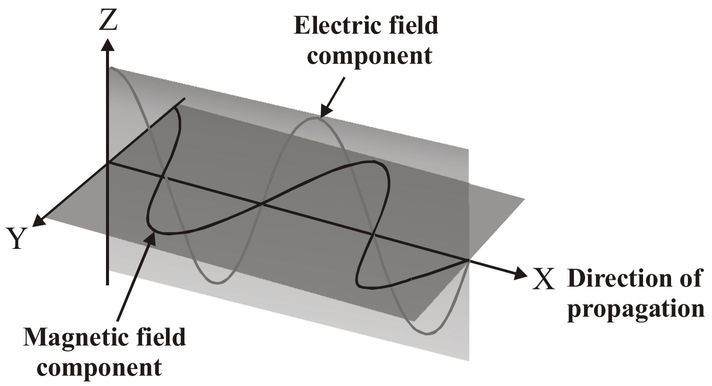
The amplitude of a wave in stretched string is the maximum displacement of the string from its normal position that of water waves is the maximum height of the water surface relative to its normal level, That of a sound wave is the maximum change in pressure relative to the normal pressure.

5.2 *ELECTRO MAGNETIC (EM) WAVES :*

James Maxwell (1870) suggested that when electrically charged particle moves under acceleration, alternating electrical and magnetic fields are produced and transmitted by it. These fields are transmitted in the forms of waves called electromagnetic waves or electromagnetic radiations.

❖ **Main assumptions of Maxwell EM theory :**

(i) The oscillating electric and magnetic fields produced by oscillating charged particles are perpendicular to each other and both are perpendicular to the direction of propagation of the wave.



(The electric and magnetic field components of an electromagnetic wave. These components have the same wavelength , frequency, speed and amplitude, but they vibrate in two mutually perpendicular planes.)

(ii) Unlike sound waves or water waves, electromagnetic waves do not require medium and can move in vacuum.

(However speed changes in different mediums)

(iii) The EM waves travel with the velocity of light (3×10^8 m/sec) in vacuum.

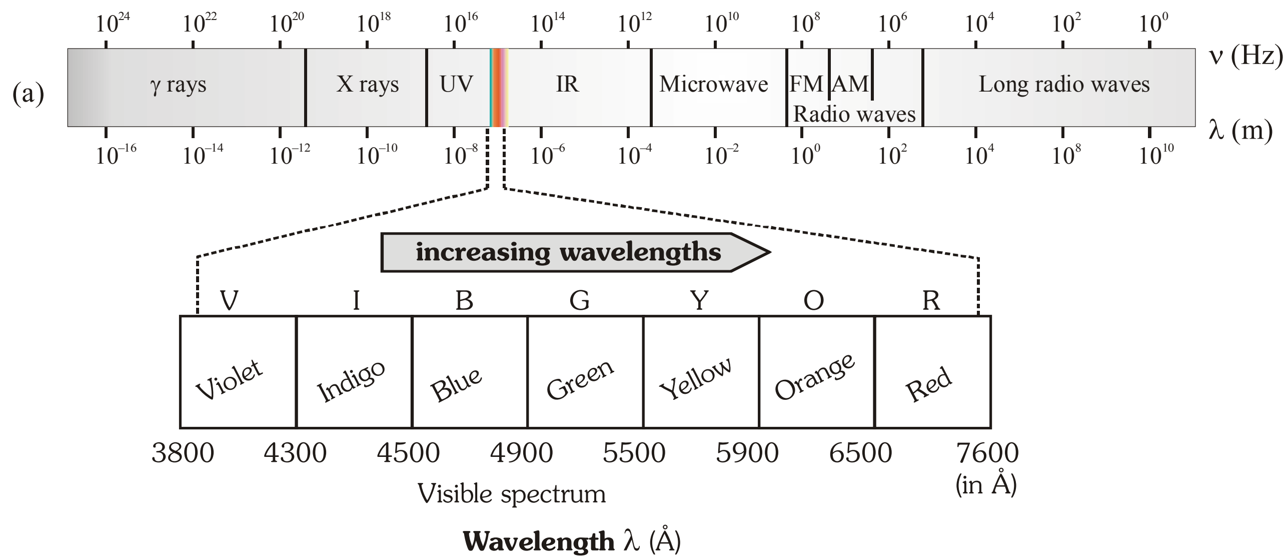
(iv) Energy of EM waves depends on its amplitude not on its frequency or wavelength.

(This assumptions was later proved to be wrong in some situations).

5.3 ELECTRO MAGNETIC SPECTRUM :

The arrangement of various types of electromagnetic radiations in the order of their increasing or decreasing wavelength or frequencies is known as electromagnetic spectrum. The wavelength decreases in the following order.

Radio waves > microwaves > Infrared > Television waves > Visible > Ultraviolet > X-rays > γ-rays > cosmic rays



(a) The spectrum of electromagnetic radiation. (b) Visible spectrum.
The visible region is only a small part of the entire spectrum.

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

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

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

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

6. PARTICLE NATURE OF ELECTROMAGNETIC RADIATIONS (PLANCK'S QUANTUM THEORY OF RADIATION)

Max Planck in 1901, put forward a theory known as **"Planck's Quantum Theory".** It regards electromagnetic radiations made up of particles. This was further extended by *Einstein* in 1905. The main points of the theory are :

(i) The radiant energy is emitted or absorbed by atoms or molecules discontinuously in the form of small energy packets called quanta. In case of light , these energy packets are known as photons.

(ii) The energy of each quantum is directly proportional to the frequency of the radiation i.e.

$$E \propto \nu \qquad \text{or} \qquad E = h\nu = \frac{hc}{\lambda}$$

Here h is a constant known as **Planck's constant.** Its value is 6.626×10^{-34} Joules sec.

(iii) The total amount of energy emitted or absorbed by a body is some whole number multiple of quantum i.e.,

$E = nh\nu$ (Here n is a positive integer : 1, 2, 3, 4 .... etc.)

Thus, Planck for the first time has given a relationship between the frequency (or wavelength) of the radiations and the energy associated with them. Cosmic rays, gamma rays and X-rays are high energy radiations since they have very high frequency. At the same time, microwaves and radiowaves with small frequency are regarded as low energy radiations.

❖ **Important features of Photon :**

- Source of energy (light) emits radiation in the form photons, which travel with speed of light.
- Energy of single photon, $E = h\nu = \frac{hc}{\lambda}$.
- All the photons in vacuum travel with speed 3×10^8 m/s but their speed is changed in different medium, however frequency remains same. Speed does not depend on energy.
- Photons travel as waves but are absorbed or emitted as particles.

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

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

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

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

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

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

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

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

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

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

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

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

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

Ex.15. The wavelength of microwave radiation is 0.08 m. How many moles of photons is needed to increase the temperature of 400 gm water from 25° to 45°C, assuming 25% efficiency.

Specific heat capacity = 4.2 J/K-gm

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

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

$\therefore$ *Number of moles of photon* $=\dfrac{n}{N_A}$

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

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

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

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

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

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

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

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

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

According to available information,

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

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

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

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

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

7. *PHOTOELECTRIC EFFECT :*

Hertz in ***1887*** 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**.

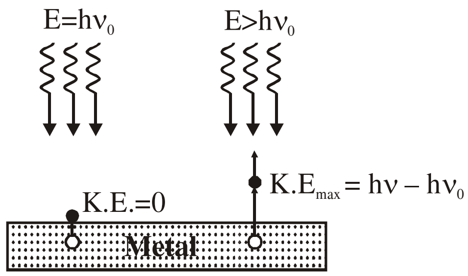
A few metals, which are having low ionisation energy like Cesium, show this effect under the action of visible light but many more show it under the action of more energetic ultraviolet light.

7.1 The experimental findings are summarized as below :

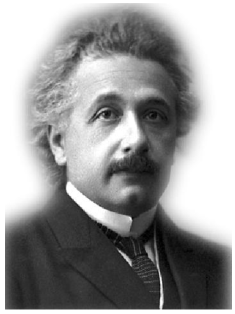
- Electrons come out as soon as the light (of sufficient energy) strikes the metal surface. There is no time lag between the two events.
- The light of any frequency will not be able to cause ejection of electrons from a metal surface. There is a minimum frequency, called the **threshold (or critical) 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 in 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.

7.2 Einstein's explanation :

Light must have stream of energy particles or quanta of energy ($h\nu$). Suppose, the threshold frequency of light required for 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 surface 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. Einstein proposed that light consisted of quanta, which we call photons with a frequency over a certain threshold would have sufficient energy to eject a single electron, producing the photoelectric effect.



Albert Einstein (1879 - 1955)

Albert Einstein, a German born American physicist, is regarded by many as one of the two great physicists the world has known (the other is Isaac Newton). His three research papers (on special relativity, Brownian motion and the photoelectric effect) which he published in 1905, **Albert Einstein (1879 - 1955)** while he was employed as a technical assistant in a Swiss patent office in Berne have profoundly influenced the development of physics. He received the Nobel Prize in Physics in 1921 for his explanation of the photoelectric effect.

7.3 Einstein's Equation for the Photoelectric Effect :

Einstein's interpretation of the photoelectric effect results in equation :

Energy of photon = Energy needed to remove an electron + Max. Kinetic energy of the emitted electron

The excess energy would give a certain velocity (i.e. kinetic energy) to the electron.

$$h\nu = h\nu_0 + K.E._{max.}$$

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

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

where ν = frequency of the incident light , ν_0 = threshould frequency

v = max. speed of photoelectron.

$h\nu_0$ 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.

The maximum 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 $h\nu_0$.

7.4 Important conclusions from photoelectric effect :

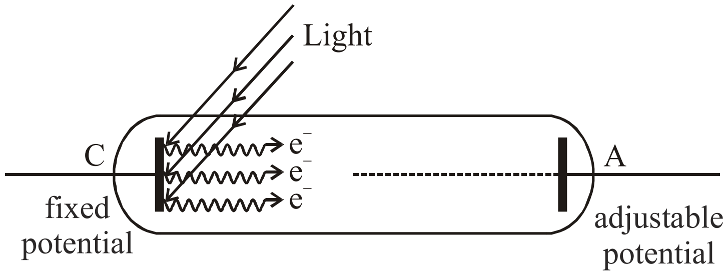
(i) Photoelectric effect demonstrates particle nature of radiation.

(ii) A photon is quanta of energy. Its rest mass is zero. This is why photon can give up its all energy to the particle it strikes.

(iii) There is no effect of frequency of incident light on the number of the emitted photoelectrons.

(iv) There is no effect of intensity of incident light on the K.E. of the emitted photoelectrons.

7.5 SATURATION CURRENT & STOPPING POTENTIAL



Case-I : $V_C = V_A$

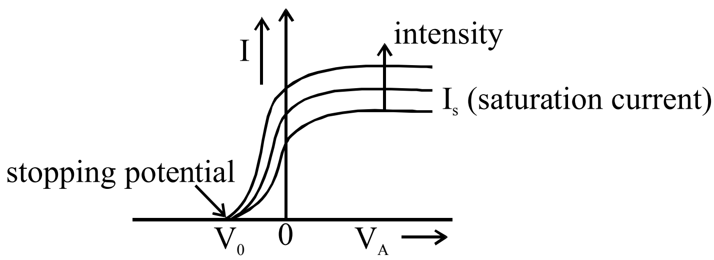
Some of the ejected electrons reach at electrode A resulting photocurrent.

Case-II : $V_C < V_A$

As electrode (A) is at high potential it attracts the electron & even a slower electron will reach at electrode A. It will result in increase in photocurrent. Further increase in the potential difference, a situation may result when the slowest photocurrent electron reach at electrode. It results maximum called **saturation current** . Further increase in potential will not increase photocurrent.

Case-III : $V_C > V_A$

As electrode (A) is at low potential. It will repel electron resulting decrease in photocurrent. Further decrease in potential at electrode (A) may result a situation when the fastest electron just fails to reach at (A) and the photocurrent drops to zero. The pontential of (A) relative to C to just stop photocurrent is called **stopping potential**.



Relative to V_C
$(V_A - V_C)$

On increasing the intensity of light the stopping potential does not change because the maximum K.E. of photoelectron does not change. But the photocurrent increases, because the number of photon falling on the surface increase.

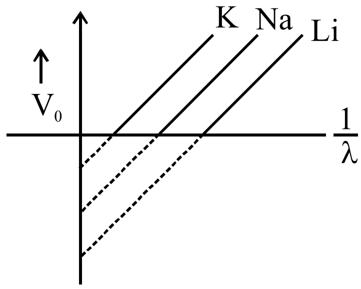
If the frequency of light is changed, the stopping potential will change.

$$(KE)_{max} = eV_0$$

$$(KE)_{max} = h\nu - h\nu_0$$

$$eV_0 = \frac{hc}{\lambda} - \phi$$

$$\underset{y}{V_0} = \frac{hc}{e}\underset{x}{\frac{1}{\lambda}} - \frac{\phi}{e}$$



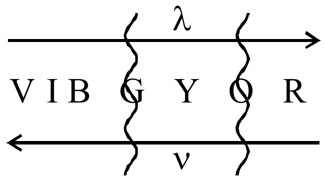
Ex.19. From a metal surface, photoelectron never comes out by orange light but comes from green light. Predict about the injection of photoelectron from the same metal by

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

Sol: *(i) Red light = No*

(ii) Blue light = Yes

(iii) Yellow light = Can't say



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

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

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

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

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

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

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

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

$2E_1 = E_2$

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

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

Sol. (i) Energy of the photon

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

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

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

(ii) Kinetic energy of the emitted photo electron

Work function = 2.20 eV

Therefore, KE = 2.475 – 2.20

= 1.925 eV = 3.08×10^{-19} J

(iii) Velocity of the photo electron

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

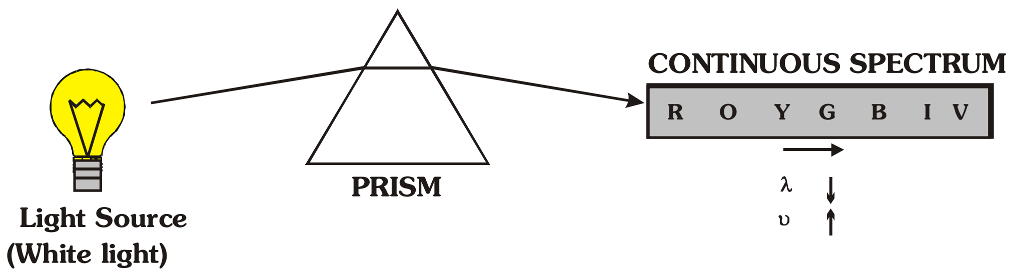
$$\text{Therefore, velocity (v)} = \sqrt{\frac{2\times3.08\times10^{-19}}{9.1\times10^{-31}}} = 8.22 \times 10^{5}\ ms^{-1}$$

8. SPECTRUM

It is the impressions produced on any screen when a light falls on it after passing through prism or prism like material.

Classification of spectrum :

(i) Continuous and discontinuous spectrum : In continuous spectrum, the impression produced on screen overlap each other, but in discontinous spectrum, same gap exist between the inpression. The spectrum of white light that we can see ranges from violet at 7.50×10^{14} Hz to red at 4×10^{14} Hz. This spectrum is called *continuous spectrum* because violet merges into blue, blue into green, and so on. A similar spectrum is produced when a rainbow forms in the sky. In a continuous spectrum, radiations corresponding to all the wavelengths are present.



(ii) Emission and Absorption Spectra : The spectrum of radiation emitted by a substance that has absorbed energy is called an **emission spectrum**. Atoms, molecules or ions that have absorbed radiation are said to be **'excited'**. To produce an emission spectrum, energy is supplied to a sample by heating it or irradiating it and the wavelength (or frequency) of the radiation emitted, as the sample gives up the absorbed energy, is recorded.

An absorption spectrum is like the photographic negative of an emission spectrum. A continuum of radiation is passed through a sample which absorbs radiation of certain wavelengths. The missing wavelength which corresponds to the radiation absorbed by the matter, leave dark spaces in the bright continuous spectrum.

The study of emission or absorption spectra is referred to as **spectroscopy**. The spectrum of the visible light, as discussed above, was continuous as all wavelengths (red to violet) of the visible light are represented in the spectra. The emission spectra of atoms in the gas phase, on the other hand, do not show a continuous spread of wavelength from red to violet, rather they emit light only at specific wavelengths with dark spaces between them. Such spectra are called **line spectra** or **atomic spectra** because the emitted radiation is identified by the appearance of bright lines in the spectra (Fig)

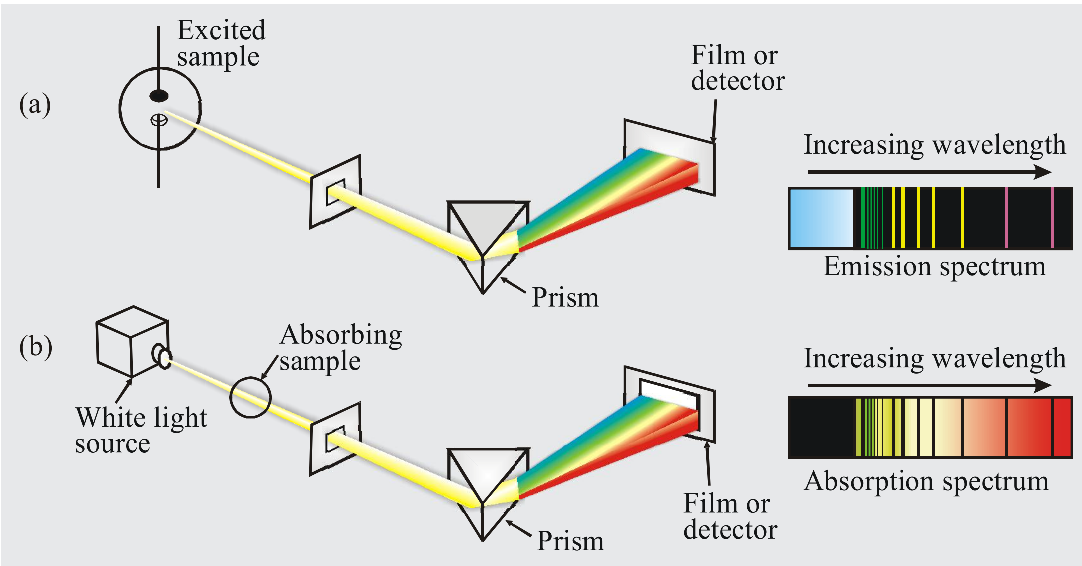


***Fig. (a) Atomic emission**. The light emitted by a sample of excited hydrogen atoms (or any other element) can be passed through a prism and separated into certain discrete wavelengths. Thus an emission spectrum, which is a photographic recording of the separated wavelengths is called as line spectrum. Any sample of reasonable size contains an enormous number of atoms. Although a single atom can be in only one excited state at a time, the collection of atoms contains all possible excited states. The light emitted as these atoms fall to lower energy states is responsible for the spectrum. **(b) Atomic absorption**. When white light is passed through unexcited atomic hydrogen and then through a slit and prism, the transmitted light is lacking in intensity at the same wavelengths as are emitted in (a) The recorded absorption spectrum is also a line spectrum and the photographic negative of the emission spectrum.*

Line emission spectra are of great interest in the study of electronic structure. Each element has a unique line emission spectrum. The characteristic lines in atomic spectra can be used in chemical analysis to identify unknown atoms in the same way as finger prints are used to identify people. The exact matching of lines of the emission spectrum of the atoms of a known element with the lines from an unknown sample quickly establishes the identity of the latter, German chemist, Robert Bunsen (1811-1899) was one of the first investigators to use line spectra to identify elements.

Elements like rubidium (Rb), caesium (Cs) thallium (Tl), indium (In), gallium (Ga) and scandium (Sc) were discovered when their minerals were analysed by spectroscopic methods. The element helium (He) was discovered in the sun by spectroscopic method.

9. BOHR'S ATOMIC MODEL

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

Niels Bohr (1885-1962)

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

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

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

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

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

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

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

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

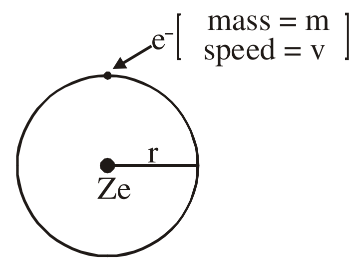
Thus an electron can move only in those orbits for which its angular momentum is integral multiple of $h/2\pi$ that is why only certain fixed orbits are allowed.

9.1 APPLICATION OF BOHR'S MODEL

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

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

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



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

In balanced condition

Electrostatic force = Centrifugal force

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

9.1.1 Radius of various orbits (shell) :

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

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

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

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

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

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

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

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

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

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

9.1.2. Velocity of electron in Bohr orbit :

According to Bohr postulate

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

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

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

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

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

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

9.1.3. Total energy of electron in Bohr orbit :

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

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

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

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

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

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

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

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

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

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

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

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

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

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

9.1.4 Some extra points :

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

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

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

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

P.E = –2 KE

KE = –T.E.

P.E = 2 T.E.

9.1.5 Important Definations :

(i) Ionization energy :

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

(ii) Separation energy :

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

(iii) Excitation energy :

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

Note : All these kinds of energy are always positive.

Ex.23. Calculate the radius of I^{st} 4 orbits of hydrogen atom

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

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

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

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

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

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

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

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

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

At. Number of He = 2

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

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

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

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

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

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

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

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

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

Sol. (i) P.E. = – 2K.E.

– 6.8 = – 2K.E.

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

(ii) E. = – K.E.

= – 3.4 eV

(iii) Orbit = 2^{nd}

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

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

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

i.e. n = 2

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

$r = 0.529 \times \frac{(2)^2}{1}$ Å

= 0.529 × 4Å = 2.16 Å

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

Sol. Ionization energy = 13.6 eV

i.e. 1^{st} energy state = – 13.6 eV

Energy of 1^{st} excited state

i.e. 2^{nd} orbit = –3.4 eV

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

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

Sol. n_1 orbit $\rightleftarrows$ n_2 orbit

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

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

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

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

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

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

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

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

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

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

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

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

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

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

No. of revolutions/sec $= \frac{1}{2\pi r / v} = \frac{v}{2\pi r} = \frac{2.18 \times 10^6\,\text{m/sec}}{2 \times 3.14 \times 1.587 \times 10^{-10}\,\text{m}}$

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

9.2 RYDBERG FORMULA

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

$$\Delta E = En_2 - En_1$$

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

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

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

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

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

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

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

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

$$\frac{1}{R} = 912Å$$

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

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

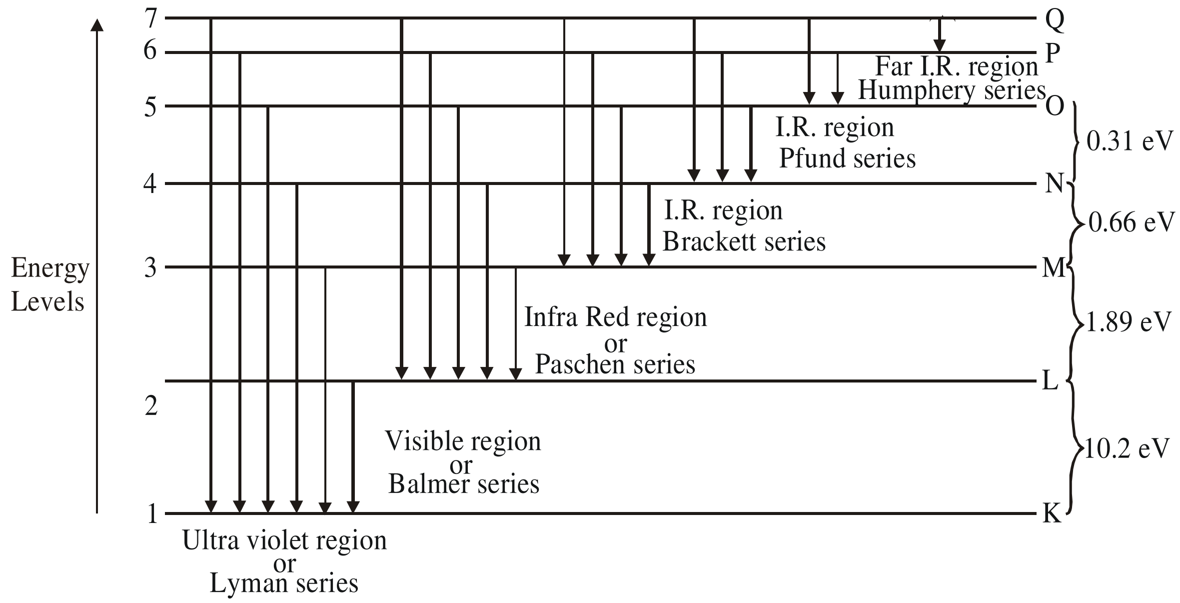
In the present case $n_2 = 4$ and $n_1 = 1$

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

$\lambda = \dfrac{1}{\bar{\nu}} = \dfrac{1}{102822}$ cm = 9.7×10^{-6} cm = $9.7 \times 10^{-6} \times 10^{7}$ nm **= 97 nm.**

9.3 *HYDROGEN LINE SPECTRUM :*

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



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

KEY POINTS :

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

  Second line of any series = β line

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

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

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

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

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

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

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

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

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

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

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

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

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

$= 10$

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

9.4 Limitation of the Bohr's model

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

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

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

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

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

10. *DUAL BEHAVIOUR OF MATTER & DE BROGLIE WAVELENGTH :*

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

de Broglie'
(1892-1987)
A French physicist, studied history as an undergraduate in the early 1910,s. His interest turned to science as a result of his assignment to radio communications in world war 1. He was awarded the Nobel Prize in physics in 1929.

$\lambda \propto \dfrac{1}{p}$ or $\lambda \propto \dfrac{1}{mv}$

$\lambda = \dfrac{h}{p}$ Here h = Planck's constant

p = momentum of electron

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

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

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

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

$E = h\nu = h \times \dfrac{c}{\lambda}$ (Planck's equation) $\left(\nu = \dfrac{c}{\lambda}\right)$ **.......(ii)**

Combining (i) and (ii)

$E = mc^2 = h \times \dfrac{c}{\lambda}$ or $mc = \dfrac{h}{\lambda}$ or $\lambda = \dfrac{h}{mc}$

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

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

10.1 DERIVATION OF BOHR'S ANGULAR MOMENTUM QUANTIZATION RULE :

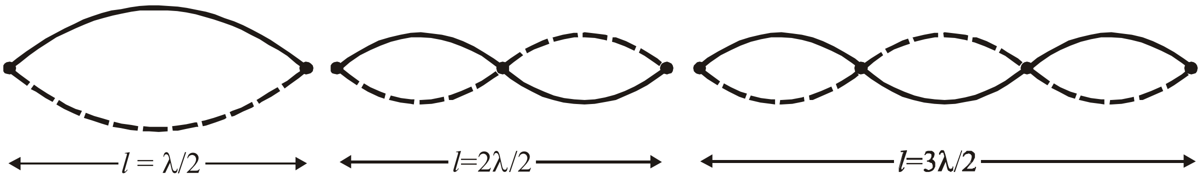
We know that according to Bohr theory, $mvr = \dfrac{nh}{2\pi}$

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

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

According to de Broglie, an electron bound to the nucleus behaves like a standing wave.

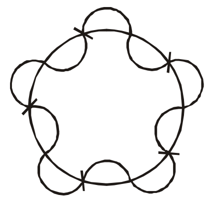
A standing wave – also known as a stationary wave – is a wave that remains in a constant position. Two opposing waves combine to form a standing wave. This phenomenon can occur because the medium is moving in the opposite direction to the wave, or it can arise in a stationary medium as a result of interference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



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

For a circular standing wave to persist, a whole number of wavelength must fit into the circumference of the circle (2π).

And if n number of waves of λ wavelength are present in this circle total circumference will be $n\lambda$.



n = 5

$\therefore$ **Waves made = 5**

$$2\pi r = n\lambda$$

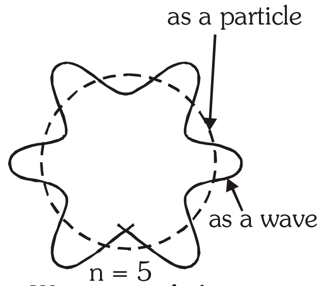
n = Number of wave made by electron in one complete revolution.

According to de Broglie

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

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

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



n = 5

Waves out of phase

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

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

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

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

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

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

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

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

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

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

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

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

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

$m = \dfrac{6.652 \times 10^{-34}}{3 \times 10^{-8} \times 5894 \times 10^{-10}}$ *or* $\dfrac{6.652}{17682} \times 10^{-32}$

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

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

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

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

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

Sol. $KE = \dfrac{9.6 \times 10^{-19}}{1.6 \times 10^{-19}} eV = 6\,eV$

$\lambda = \sqrt{\dfrac{150}{6}}Å = 5Å$

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

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

(i) Moving at same speed

(ii) Moving at same momentum

(iii) Having same K.E.

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

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

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

$$\frac{\lambda_{electron}}{\lambda_\alpha} = \frac{m_\alpha}{m_e} = \frac{4 \times 1836}{1}$$

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

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

$$\lambda = \frac{h}{\sqrt{2mE}} = \frac{\lambda_e}{\lambda_\alpha} = \sqrt{\frac{m_\alpha}{m_e}} = \sqrt{\frac{1836 \times 4}{1}}$$

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

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

Sol. $\Delta E = 13.6 \times 9\left(1-\frac{1}{4}\right) = 91.8 eV$

Excess energy = 91.8 – 13.6 = 78.2 eV

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

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

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

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

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

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

$mv = 9.51 \times 10^{-25} \Rightarrow \lambda = \frac{h}{mv} = \frac{6.626\times10^{-34}}{9.51\times10^{-25}} = 0.696 \times 10^{-9} \text{ m}$

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

Sol. (i) $\lambda = \sqrt{\frac{150}{V\times1836}}\text{Å} = \sqrt{\frac{150}{750\times1836}}\text{Å}$

10.2 Justification of dual nature of electrons :

I. Particle character :

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

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

II. Wave character :

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

11 HEISENBERG UNCERTAINTY PRINCIPLE :

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

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

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

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

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

where h is Planck's constant.

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

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

$$\Delta x \,.\, \Delta v \geq \frac{6.624 \times 10^{-27}}{4\pi m} \geq \frac{6.624 \times 10^{-27}}{4 \times 3.14 \times 9.10 \times 10^{-28}}$$

= 0.57 erg sec per gram approximately

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

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

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

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

The uncertainty in the speed,

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

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

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

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

Sol. Mass of ball ,

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

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

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

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

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

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

12 QUANTUM MECHANICAL MODEL OF ATOM

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

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

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

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

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

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

12.1 ***Hydrogen Atom and the Schrodinger Equation***

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

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

Erwin Schrodinger (1887-1961)

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

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

Application of Schrodinger equation to multi-electron atoms presents a difficulty: the Schrodinger equation cannot be solved exactly for a multi-electron atom. This difficulty can be overcome by using approximate methods. Such calculations with the aid of modern computers show that orbitals in atoms other than hydrogen do not differ in any radical way from the hydrogen orbitals discussed above.

The principal difference lies in the consequence of increased nuclear charge. Because of this all the orbitals are somewhat contracted. Further, as you shall see later , unlike orbitals of hydrogen or hydrogen like species, whose energies depend only on the quantum number n, the energies of the orbitals in multi-electron atoms depend on quantum numbers *n* and *l*.

12.2 Important Features of the Quantum Mechanical Model of Atom–

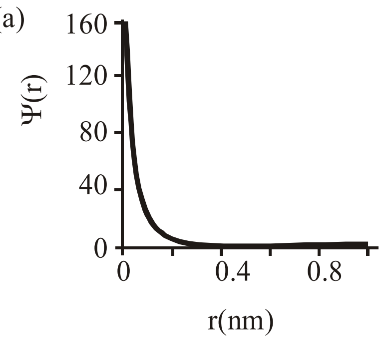
Quantum mechanical model of atom is the picture of the structure of the atom, which emerges from the application of the Schrodinger equation to atoms. The following are the important features of the quantummechanical model of atom:

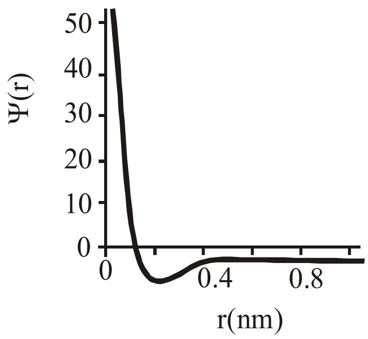
1. The energy of electrons in atoms is quantized (i.e., can only have certain specific values), for example when electrons are bound to the nucleus in atoms.
2. The existence of quantized electronic energy levels is a direct result of the wave like properties of electrons and are allowed solutions of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

12.3 Shapes of Atomic Orbitals

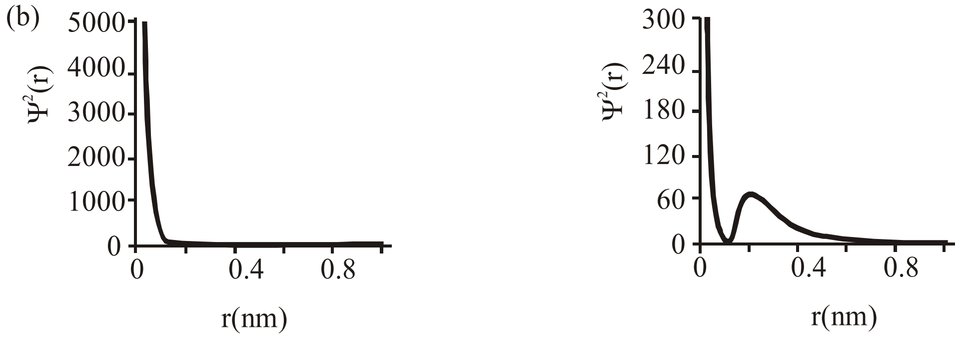
The orbital wave function or ψ for an electron in an atom has no physical meaning. It is simply a mathematical function of the coordinates of the electron. However, for different orbitals the plots of corresponding wave functions as a function of r (the distance from the nucleus) are different. Such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

(a)



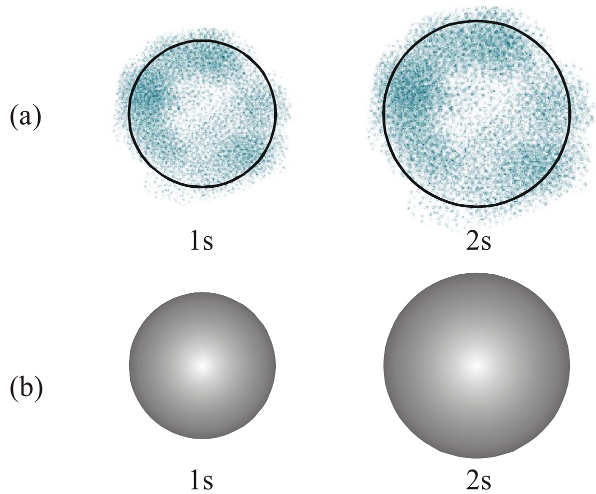


According to the German physicist, Max Born, the square of the wave function (i.e., ψ^2) at a point gives the probability density of the electron at that point. The variation of ψ^2 as a function of r for 1s and 2s orbitals is given in fig. Here again, you may note that the curves for 1s and 2s orbitals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



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

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

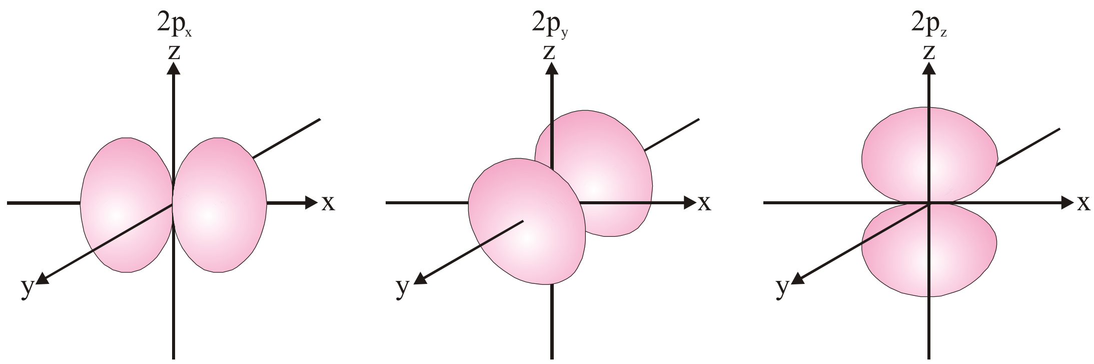


(a) Probability density plots of 1s and 2s atomic orbitals. The density of the dots represents the probability density of finding the electron in that region. (b) Boundary surface diagram for 1s and 2s orbitals.

Boundary surface diagrams of constant probability density for different orbitals give a fairly good representation of the shapes of the orbitals. In this representation, a boundary surface or contour surface is drawn in space for an orbital on which the value of probability density $|\psi|^2$ is constant. In principle many such boundary surfaces may be possible. However, for a given orbital, only that boundary surface diagram of constant probability density is taken to be good representation of the shape of the orbital which encloses a region or volume in which the probability of finding the electron is very high, say, 90%.

The boundary surface diagram for 1s and 2s orbitals are given in fig. One may ask a question : Why do we not draw a boundary surface diagram, which bounds a region in which the probability of finding the electron is, 100 %? The answer to this question is that the probability density $|\psi|^2$ has always some value, howsoever small it may be, at any finite distance from the nucleus. It is therefore, not possible to draw a boundary surface diagram of a rigid size in which the probability of finding the electron is 100%. Boundary surface diagram for a s orbital is actually a sphere centred on the nucleus. In two dimensions, this sphere looks like a circle. It encloses a region in which probability of finding the electron is about 90%.

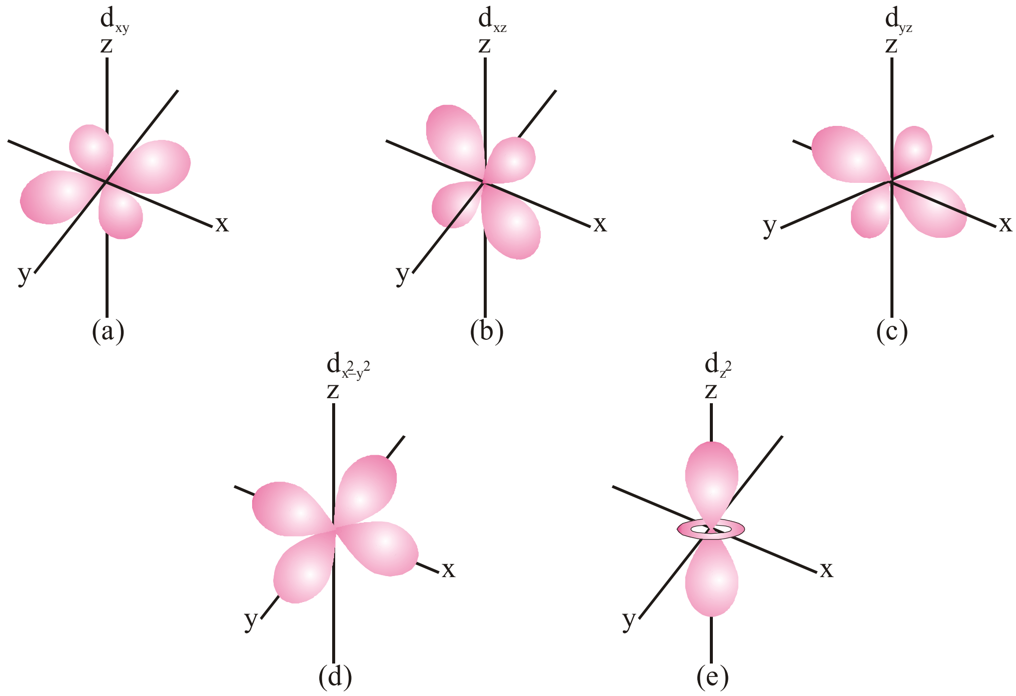
Thus we see that 1s and 2s orbitals are spherical in shape. In reality all the s-orbitals are spherically symmetric, that is, the probability of finding the electron at a given distance is equal in all the directions. It is also observed that the size of the s orbital increases with increase in n, that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



Boundary surface diagrams of the three 2p orbitals.

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

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



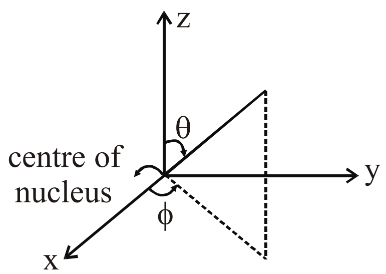
Boundary surface diagrams of the five 3d orbitals.

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

Besides the radial nodes (i.e., probability density function is zero), the probability density functions for the np and nd orbitals are zero at the plane (s), passing through the nucleus (origin). For example, in case of p_z orbital, xy-plane is a nodal plane, in case of d_{xy} orbital, there are two nodal planes passing through the origin and bisecting the xy plane containing z-axis. These are called **angular nodes** and number of angular nodes are given by 'l', i.e., one angular node for p orbitals, two angular nodes for 'd' orbitals and so on.

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

12.4 SOLUTION OF SCHRODINGER EQUATION :



Spherical coordinate system

The solution in spherical coordinates may be represented as :

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

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

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

12.4.1 Radical part of solution :

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

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

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

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

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

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

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

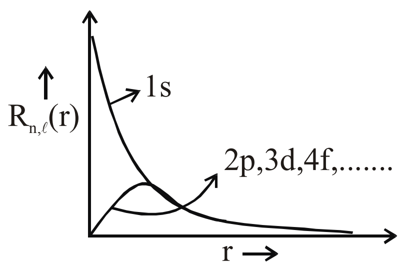
General form :

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

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

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

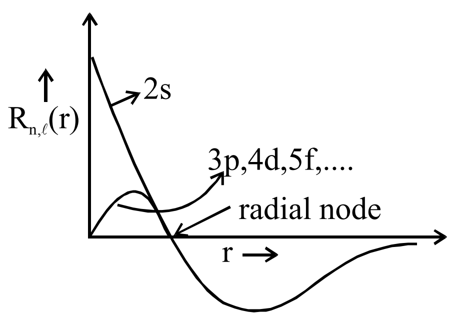
(i)



$n - \ell - 1 = 0$

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

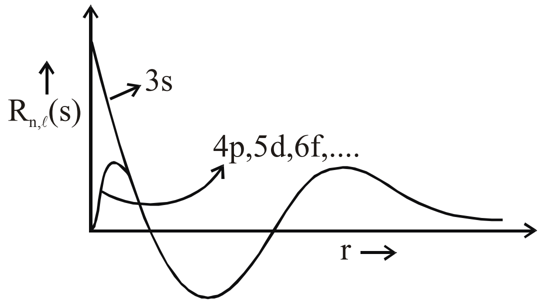
(ii)



$n - \ell - 1 = 1$

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

(iii)

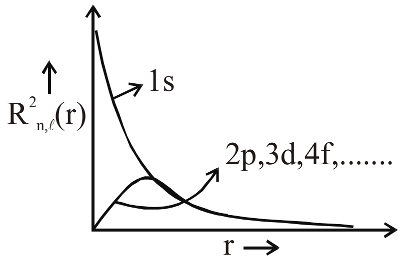


$n - \ell - 1 = 2$

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

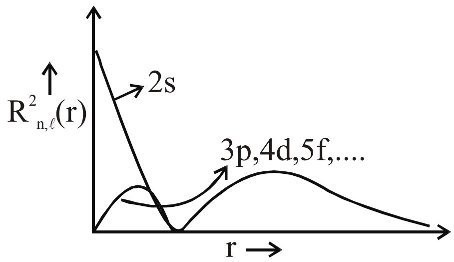
12.4.3 GRAPH OF RADIAL PROBABLITY DENSITY FUNCTION [$R^2(r)$ or $\psi^2(r)$] :

(i)



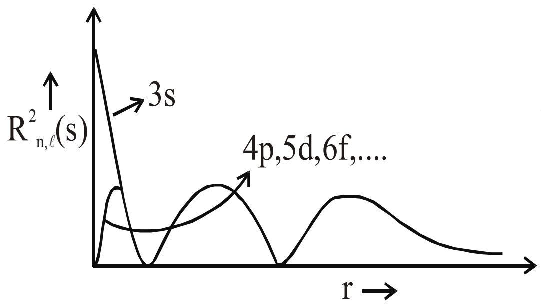
$n - \ell - 1 = 0$, (1s, 2p, 3d, 4f .....orbitals)

(ii)



$n - \ell - 1 = 1$ (2s, 3p, 4d, 5f .....orbitals)

(iii)



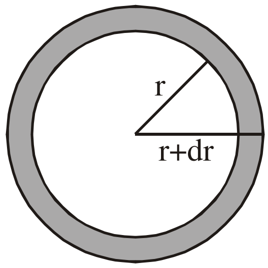
$n - \ell - 1 = 2$ (3s, 5p, 5d, 6f ...... orbitals)

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

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

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

❖ **Volume of radial shell :**



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

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

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

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

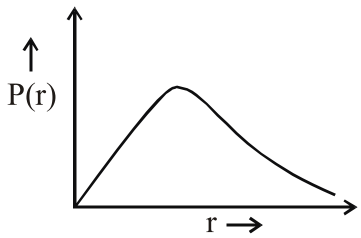
$\therefore$ Volume of shell, $dV = \frac{4}{3}(\pi \times 3r^2dr) = 4\pi r^2 dr$

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

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

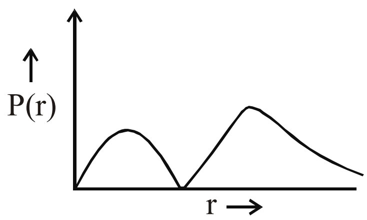
$P = R^2(r).\ dV = R^2(r).4\pi r^2.dr$

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

(i) 

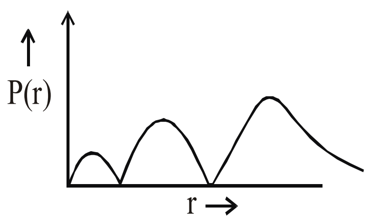
$n - \ell - 1 = 0$

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

(ii) 

$n - \ell - 1 = 1$

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

(iii) 

$n - \ell - 1 = 2$

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

❖ **Chracteristics of radial distribution function :**

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

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

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

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

12.5 ANGULAR PART OF SOLUTION :

(1) s-orbital :

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

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

(2) p-orbital :

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

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

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

(3) d-orbital :

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

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

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

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

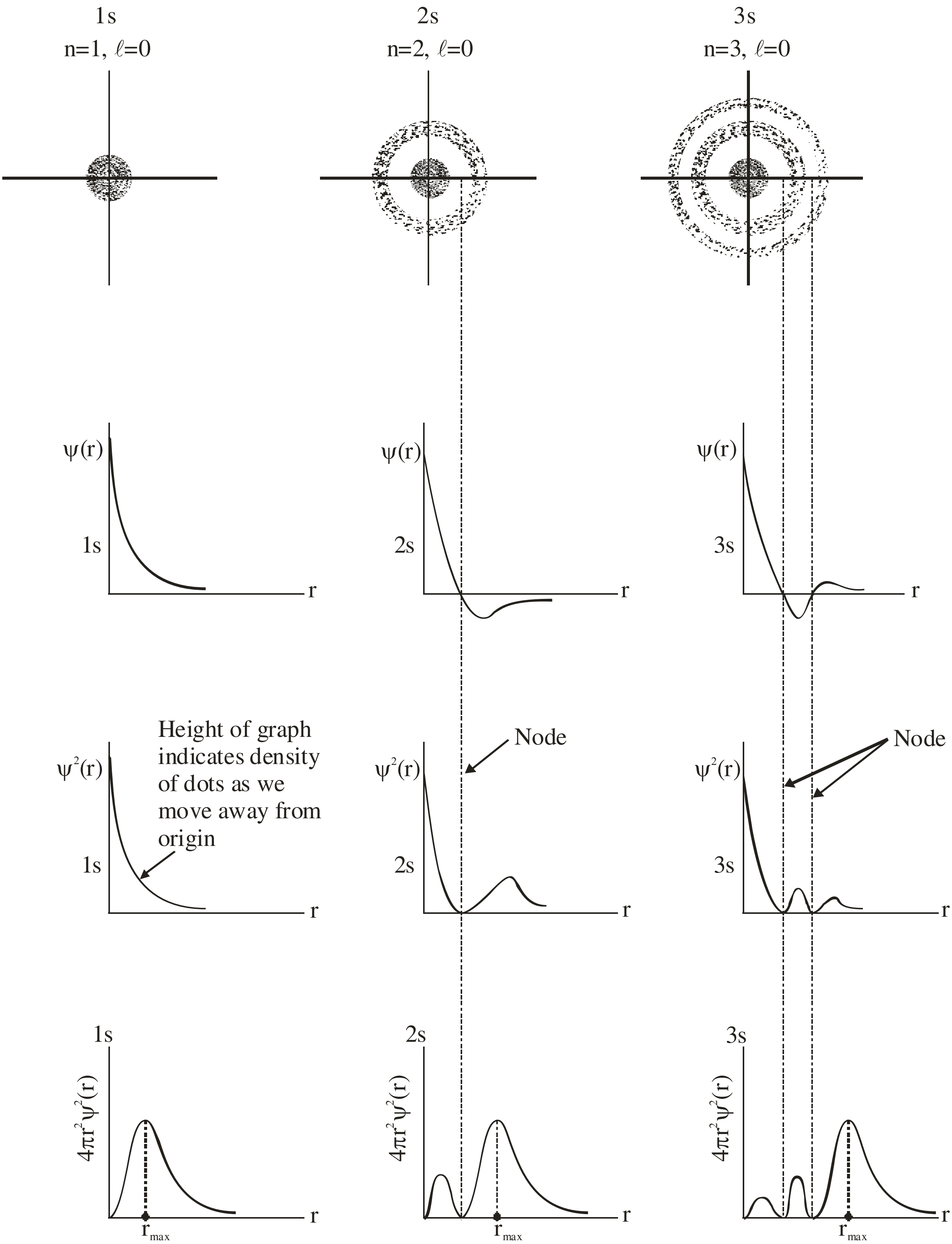
d_{yz} -orbital : $\ell = 2, m = +1$ $\quad\Theta(\theta) \,.\, \Phi(\phi) = \sqrt{\dfrac{15}{4\pi}} \cdot \sin\theta\cos\theta \cdot \sin\phi$

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

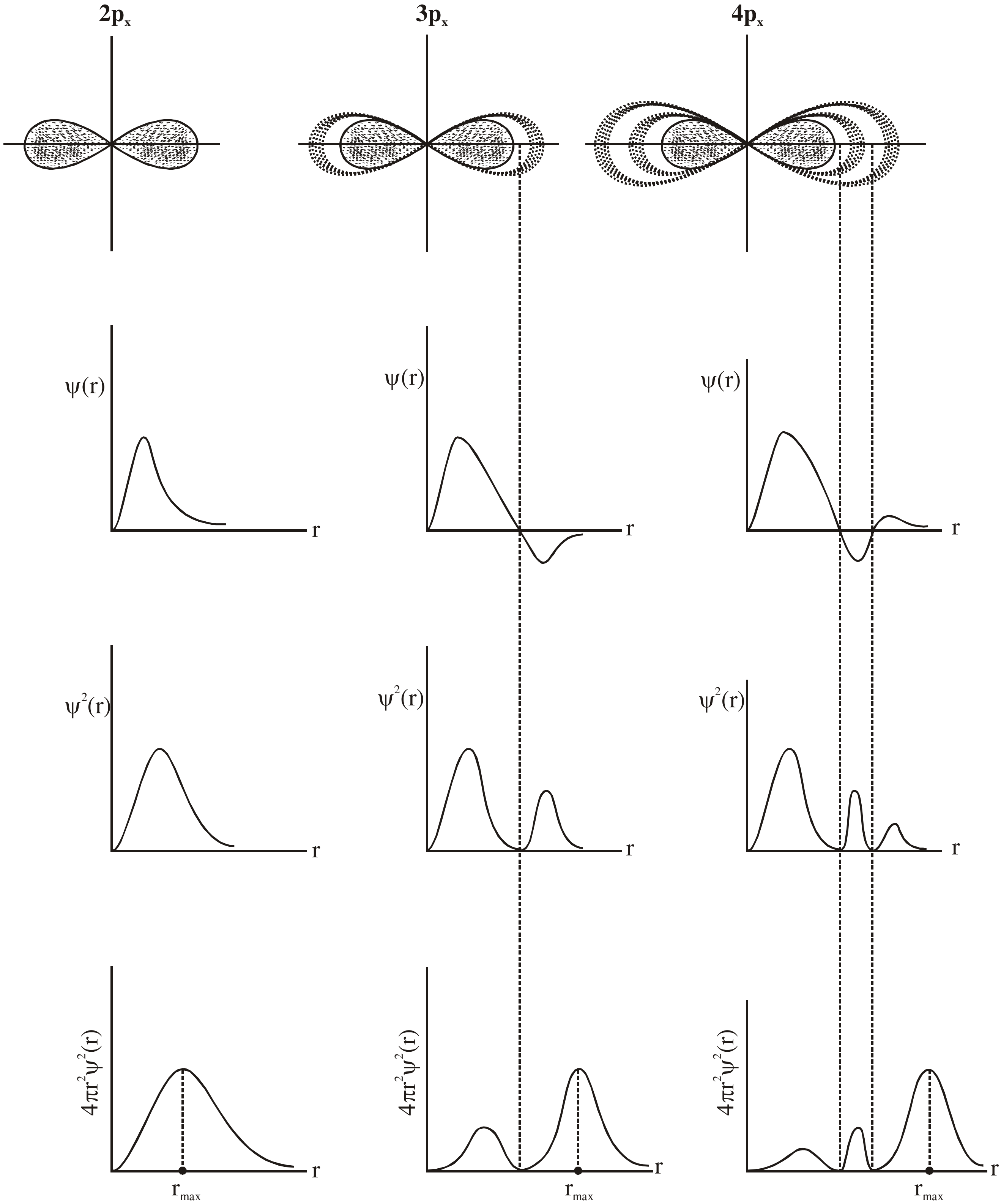
Number of angular nodes = ℓ

Total of number nodes = $n - 1$

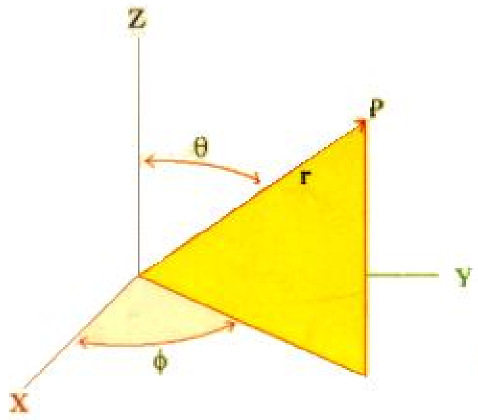
12.6 Electron-density distribution in 1s, 2s and 3s-orbitals. The lower part of the fig. shows how the electron density, represented by ψ^2 varies as a function of distance from the nucleus. In the 2s and 3s - orbitals, the electron-density function drops to zero at certain distances from the nucleus.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



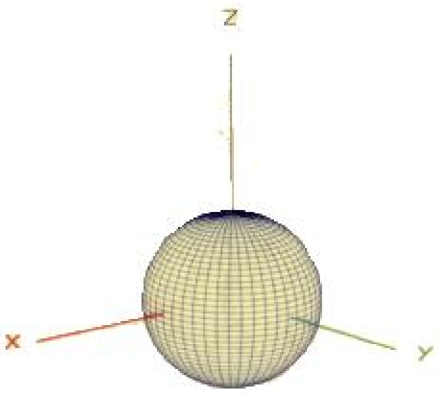
12.7 Electron-density distribution in $2p_x$, $3p_x$ and $4p_x$-orbitals :



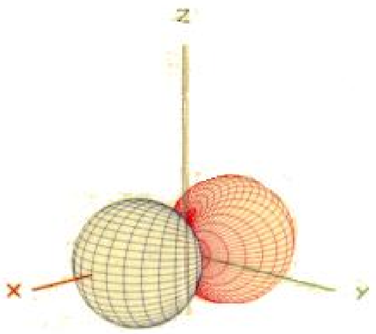
12.8 SHAPES OF ATOMIC ORBITALS



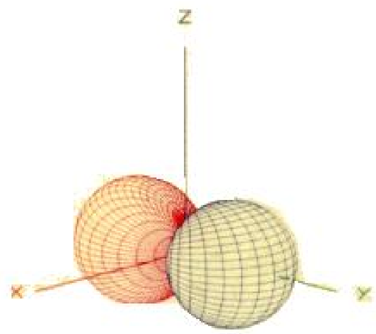
The spherical Polar Coordinates



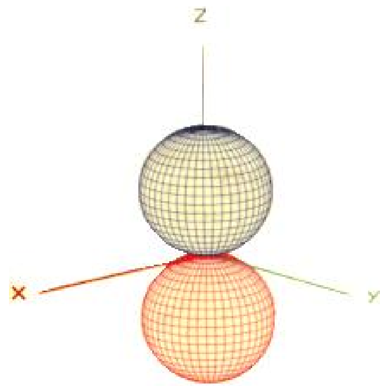
S



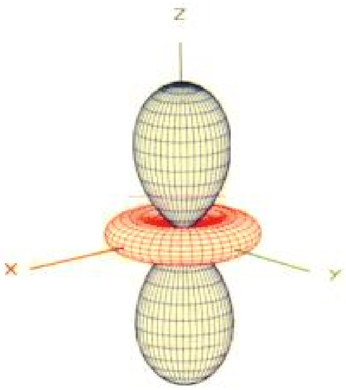
p_X



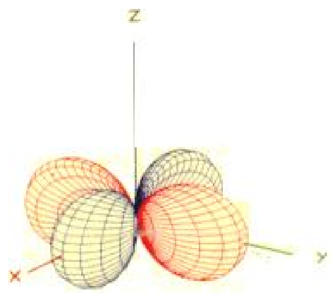
p_y



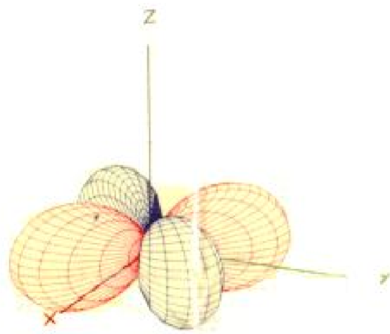
p_z



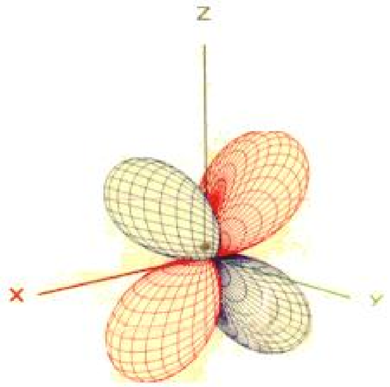
d_{z^2}



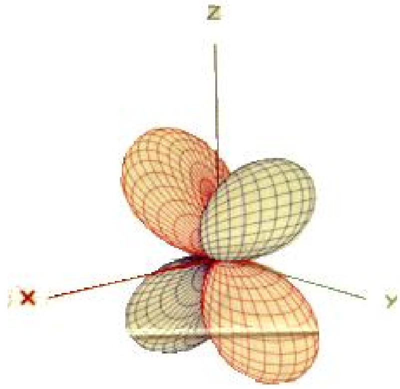
$d_{x^2-y^2}$



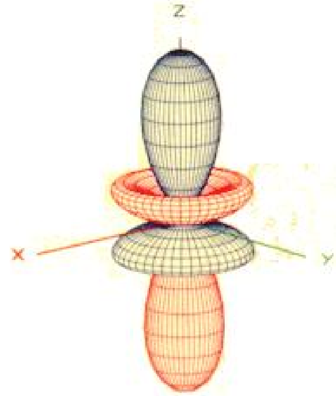
d_{xy}



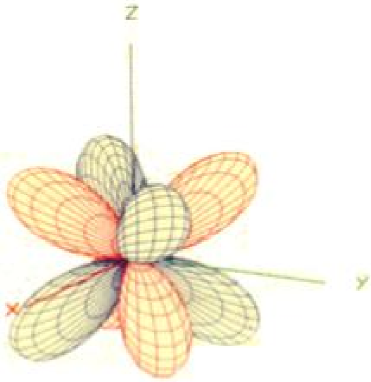
d_{xz}



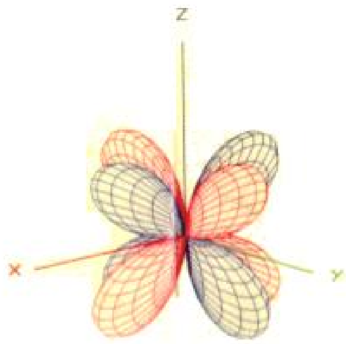
d_{yz}



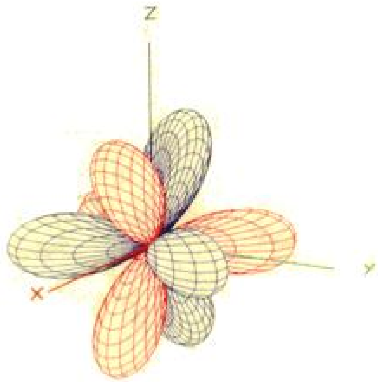
f_{z^3}



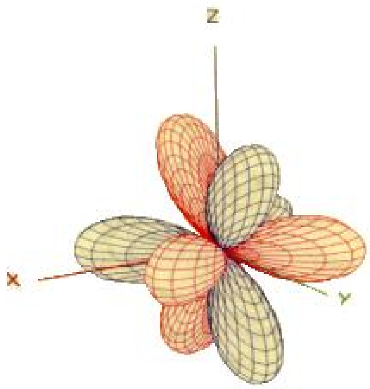
f_{xyz}



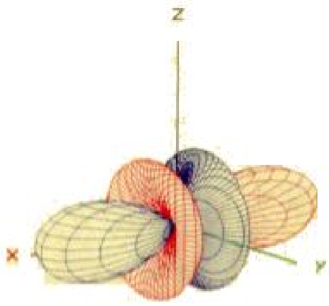
$f_{z(x^2-y^2)}$



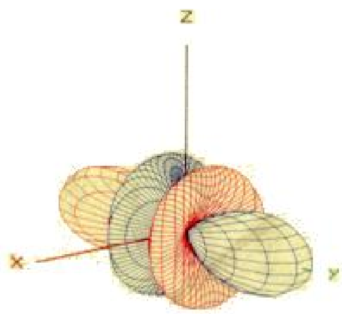
$f_{x(y^2-z^2)}$



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



f_{x^3}



f_{y^3}

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

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

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

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

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

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

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

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

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

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

Sol. $R(r) = 0$

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

SOME PREVIOUS YEARS QUESTION

1. With what velocity should an α–particle travel towards the nucleus of a Cu atom so as to arrive at a distance 10^{-13} m . **[JEE 1997]**

Ans. **6.3 × 10^{6} m/s**

Sol. $\frac{1}{2}mv^2 = \frac{kq_1q_2}{r}$

$v^2 = \frac{2kq_1q_2}{mr}$

$= \frac{2 \times 9 \times 10^9 \times 2e \times 29e}{(10^{-13})\ (1.67 \times 10^{-27})}$

$= \frac{18 \times 2 \times 29 \times 10^9 \times (1.6)^2 \times 10^{-38}}{1.67 \times 10^{-23} \times 10^{-27}}$

$= \frac{36 \times 29 \times 2.56 \times 10^{-29+40}}{1.67}$

$= 1600.3 \times 10^{11}$

2. A compound of Vanadium has magnetic moment of 1.73 BM work out electronic configuration of Vanadium Ion in the compound. **[JEE 1997]**

Ans. **[Ar] 3d^{1}**

Sol. $r = \sqrt{n(n+2)}$ $n = 1$

$= \sqrt{3}$

$= 1.73$ [Ar] $3d^2$

3. The energy of an electron in the first Bohr orbit of H atom is – 13.6 eV . The possible energy value(s) of the excited state(s) for electrons in Bohr orbits of hydrogen is/are :

(A) – 3.4 eV (B) – 4.2 eV (C) – 6.8 eV (D) + 6.8 eV **[JEE 1998]**

Ans. **(A)**

Sol. $E = -13.6$

$E = \frac{-13.6}{4} = -3.4$ eV

4. The number of nodal planes in a p_x orbital is: **[JEE 2000]**

(A) one (B) two (C) three (D) zero

Ans. **(A)**

Sol. **One**

5. Calculate the energy required to excite one litre of hydrogen gas at 1 atmp and 298K to the first excited state of atomic hydrogen. The energy for the dissociation of H – H is 436 KJ mol^{-1}.

Ans. **97.819 KJ**

Sol. E = 436

T = 298 K

p = 1 atm   Energy req. $= 436 \times \dfrac{1}{298 \times R}$

u = 1ℓ $E = \left(10.2 \times 96.47 \times \dfrac{2}{R \times 298}\right) + \left(\dfrac{436}{R \times 298}\right)$

$n = \dfrac{1}{298R} = \dfrac{2 \times 04 \times 96.47 \times 436}{298 \times R}$

6. 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.

Ans. **(D)**

Sol. Two quantum mechanical spin states which have no classical analogue.

7. Rutherfords experiment , which established the nuclear model of atom, used a beam of :–

(A) β - particles, which impinged on a metal foil and get absorbed. **[JEE 2002]**

(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 nuclie, which impinged on a metal foil and got scattered.

Ans. **(D)**

Sol. Helium nuclie, which impinged on a metal foil and got scattered.

8. The magnetic moment of cobalt of the compund $Hg[Co(SCN)_4]$ is [Given : Co^{+2}]

(A) $\sqrt{3}$ (B) $\sqrt{8}$ (C) $\sqrt{15}$ (D) $\sqrt{24}$ **[JEE 2004]**

Ans. **(C)**

Sol. Co^{+2}

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^7$

n = 3

$r = \sqrt{n(n+2)}$

$= \sqrt{3 \times 5} = \sqrt{15}$

9. The radius of which of the following orbit is same as that of the first Bohr's orbit of hydrogen atom?

(A) He^{+} (n = 2) (B) Li^{2+} (n = 2) (C) Li^{2+} (n = 3) (D) Be^{3+} (n = 2) **[JEE 2004]**

Ans. **(D)**

Sol. $r = 0.529 \times \frac{n^2}{z}$ $r_H = 0.529$

$r_{He^+} = 0.529 \times \frac{4}{2}$ $r_{Li^{+2}} = 0.529 \times \frac{9}{3}$

$r_{Li^{+2}} = 0.529 \times \frac{4}{3}$ $r_{Be^{+3}} = 0.529 \times \frac{4}{4} = r_H$

10. (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 rdial 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.

Ans. **(a) $r_0 = 2a_0$, (b) 6.626×10^{-25} Å**

Sol. $\Psi_{2s} = \frac{1}{4(2\pi)^{1/2}}\left(\frac{1}{a_0}\right)^{3/2}\left(2-\frac{r_0}{a_0}\right)e^{-r/a}$

(b) $\lambda = \frac{h}{mv}$ (a) $2-\frac{r_0}{a_0} = 0$

$= \frac{6.626\times10^{-34}}{(0.1)(100)}$ $\frac{r_0}{a_0} = 2$

$= 6.626 \times 10^{-35}$ m $r_0 = 2a_0$

$= 6.626 \times 10^{-35} \times 10^{+10}$

$= 6.626 \times 10^{-25}$ Å

11. (a) Calculate velocity of electron in first Bohr orbit of hydrogen atom (Given $r = a_0$) **[IIT-2005]**

(b) Find de-Broglie wavelength of the electron in first Bohr orbit.

(c) Find the orbital angular momentum of 2p-orbital in terms of $h/2\pi$ units.

Ans. **(a) 2.197×10^6 m/s (b) 3.31 Å (c) $\sqrt{2}.\frac{h}{2\pi}$**

Sol. (a) $v = 2.188\times10^6 \times \frac{1}{1}$ m/s (b) $\lambda = \frac{h}{mv}$

$= \frac{6.626\times10^{-34}}{9.1\times10^{-31}\times2.188\times10^{6}}$

$= 0.332 \times 10^{-9}$ m

$= 3.31 \times 10^{-10}$ m

$= 3.31$ Å

(c) $\sqrt{\ell(\ell+1)}\dfrac{h}{2\pi}$

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

12. 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)	$U = \dfrac{V_n}{K_n}$	(P)	1
(B)	$\dfrac{1}{r_n} \propto E^x$	(Q)	–2
(C)	$r_n \propto Z^y$ (Z = Atomic number)	(R)	–1
(D)	v = (Orbital angular momentum of electron in its lowest energy)	(S)	0

Ans. (A) - Q ; (B) - P ; (C) - R ; (D) - S

Sol. (A) $U = \dfrac{V_n}{K_n}$

$= \dfrac{-27.2}{13.6} = -2$

(B) $\dfrac{1}{r_n} \propto E^x$

(C) $r_n \propto Z^y$

$0.529\ n^2/z = (z)^y$

13. 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 in hydrogen-like atom	(S)	Electron spin quantum number

Ans. (A) - Q,R ; (B) - P,Q,R,S ; (C) - P,Q,R ; (D) - P,Q

Sol. (A) (Q) Azimuthal quantum number
(R) Magnetic quantum number

(B) (P) Principal quantum number
(Q) Azimuthal quantum number
(R) Magnetic quantum number
(S) spin quantum number

(C) (P) Principal quantum number
(Q) Azimuthal quantum number
(R) Magnetic quantum number

(D) (P) Principal quantum number
(Q) Azimuthal quantum number

EXERCISE # S-I

FUNDAMENTAL PARTICLES

1. Find the ratio of specific charges $\left(\frac{q}{m}\right)$ of an α-particle and a deuteron

AS0001

2. Specific charges of two particles A and B are in ratio 2 : 3. If their mass ratio $m_A : m_B$ is 2 : 3, then find ratio of their charges $\left(\frac{q_A}{q_B}\right)$?

AS0002

3. Arrange electron (e), proton (p) , neutron (n) and α-particles (α) , in the increasing order of their e/m ratio.

AS0003

4. In oil drop experiment, the following charges were experimentally determined for five oil droplets 1.2×10^{-18} unit, 3.0×10^{-18} unit, 6.0×10^{-18} unit, 2.4×10^{-18} unit and 3.6×10^{-18} unit (unit is arbitrary). What should be the charge on electron in this arbitrary unit ?

AS0004

5. The kinetic energy of a charged particle (charge = q) accelerated by a potential difference of 10000 volt is 1.6×10^{-15} Joule. The value of 'q' is.

AS0005

RUTHERFORD'S ATOMIC MODEL

6. If the radius of an atom is 2Å and the radius of its nucleus is 4×10^{-15} m. The ratio of volume of nucleus to that of atom is.

AS0006

7. Radius of nucleus may be given as $R_N = R_0.A^{1/3}$, where A = mass number and R_0 = constant. Calculate the density of nucleus of an atom if $R_0 = 1.2 \times 10^{-15}$.
[$N_A = 6 \times 10^{23}$, $23 \times 8\pi \times (1.2)^3 = 1000$]

AS0007

8. The ratio of distances of closest approach of a proton and an α-particle projected towards the same nucleus with the same initial kinetic energy is.

AS0008

9. An α-particle of K.E. 5.4 MeV is projected towards Cr-nucleus (Z = 24). What is its distance of closest approach ? ($e = 1.6 \times 10^{-19}$C)

AS0009

10. With what speed an α-particle should be projected towards stationary krypton nucleus (Z = 36) such that it approaches upto 2.4×10^{-14}m from the nucleus ? ($N_A = 6 \times 10^{23}$, $e = 1.6 \times 10^{-19}$C).

AS0010

WAVE CHARACTERISTICS

11. Calculate the wave length of an electromagnetic radiation of frequency 2×10^{15} Hz.

AS0011

12. A radiostation emits the radiations of wavelength 2000 m (meter band of station). What is the frequency band of that station (Frequency of emitted radio waves) ?

AS0012

13. The wave numbers of two electromagnetic radiations are $4 \times 10^6\ m^{-1}$ and $2 \times 10^5\ cm^{-1}$. The ratio of their frequencies is.

AS0013

14. An electromagnetic radiation makes 5000 waves in 20 cm. The frequency of radiation is.

AS0014

PLANCK'S QUANTUM THEORY

15. Calculate the energy in Joule of a photon of wave length 4000 Å.

AS0015

16. 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 662 nm . If a total energy of 3.0×10^{-14} J is required to trip the signal, what is the minimum number of photons that must strike the receptor. ($h = 6.62 \times 10^{-34}\ J \times s$)

AS0016

17. Find the number of photons of radiation of frequency $5 \times 10^{13}\ s^{-1}$ that must be absorbed in order to melt one gm ice when the latent heat of fusion of ice is 330 J/g. ($h = 6.6 \times 10^{-34}$ J × sec.)

AS0017

18. A certain dye absorbs 4000 Å and fluoresces at 5000 Å these being wavelengths of maximum absorption that under given conditions 40% of the absorbed energy is emitted. Calculate the ratio of the number of quanta emitted to the number absorbed.

AS0018

19. 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.

$$\left(1\frac{\text{eV}}{\text{atom}} = 96\text{kJ}/\text{mol}\ ;\ \text{hc} = 1240\ \text{ev} \times \text{nm}\right)$$

AS0019

20. 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. ($N_A = 6 \times 10^{23}$)

AS0020

PHOTOELECTRIC EFFECT

21. The minimum energy required for the emission of a metal electron is 13.24×10^{-19} J. Calculate the critical frequency and the corresponding wavelength of the photon (threshold wavelength) required to eject the electron ?

AS0021

22. A light source of wavelength λ illuminates a metal and ejects photo electron with $(KE)_{max} = 1$ eV. Another light source of wave length $\frac{\lambda}{3}$, ejects photoelectrons from same metal with $(KE)_{max}$=5eV. Find the value of work function (eV) of metal.

AS0022

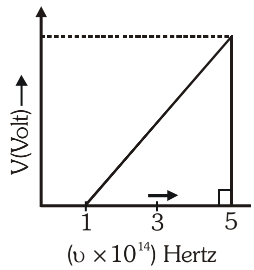
23. The dissociation energy of H_2 is 482.5 KJ/mol. If H_2 is exposed to radiant energy of wavelength 124 nm, what % of radiant energy will be converted into K.E. ($1\frac{\text{ev}}{\text{atom}}$ = 96.5 kJ/mol.)

AS0023

24. The K.E. of an electron emitted from tungstan surface is 3.06 eV. What voltage would be required to bring the electron to rest.

AS0024

25. Stopping potential [V volts] is plotted against frequency of light used [υ].
Find work function (eV). (h = 6.62×10^{-34} J × s)



AS0025

BOHR'S MODEL

26. If the mass of electron is doubled, then find the new radius (in Å) of 1st orbit of H-atom ?

AS0026

27. If an electron in H-atom jumps from one orbit to other its angular momentum doubles. If the new radius is 'x' times the old radius, then find x ?

AS0027

28. The radius of the an orbit of hydrogen atom is 0.85 nm. Calculate the velocity (in m/sec) of electron in this orbit.

AS0028

29. 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 no. "n" of the orbit and the wave no. of the radiation emitted for the transition from the quatum state (n+1) to the ground state.

AS0029

30. 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.

AS0030

31. Calculate the frequency of e^- in the first Bohr orbit in a H-atom.

AS0031

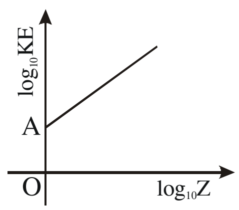
32. Calculate energy (in J) of electron which is moving in the orbit of a hydrogen atom that has its radius, sixteen times the radius of first Bohr orbit for H–atom.

AS0032

33. The energy of an excited H-atom is –3.4 eV. Calculate angular momentum of e^- in the given orbit.

AS0033

34. In a H-like atom for an electron revolving in n^{th} orbit, the variation of $\mathbf{log_{10}}$ **KE** versus $\mathbf{log_{10}Z}$ 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.

AS0034

35. The energy of the second stationary state in Li^{+2} ion is -11.025×10^{-18} J. Find ionization energy (in J/mole) for He^+ ions in its ground state :

AS0035

36. The energy of an electron in the first orbit of He^+ is -871.6×10^{-20} J. The energy of the electron in the first orbit of hydrogen would be :

AS0036

37. A single electron orbits around a stationary nucleus of charge +Ze where Z is atomic number and 'e' is the magnitude of the electric charge. The hydrogen like species required 47.2 eV to excite the electron from the second Bohr orbit to the third Bohr orbit. Find

(i) the value of Z and give the hydrogen like species formed.

(ii) the kinetic energy (in eV) and potential energy (in eV) of the electron in the first Bohr orbit.

AS0037

38. A hydrogen like atom with atomic number 'Z' is in higher excited state of quantum number 'n'.This xcited state atom can make a transition to the first excited state by successively emitting two photons of energies 10 eV and 68.2 eV respectivley. 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'.

AS0038

39. H-atom is exposed to electromagnetic radiation of 1026 Å and gives out induced radiations (radiations emitted when e^- returns to ground state).Calculate λ (in Å) of induced radiations.

AS0039

40. 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 $\lambda = 3.0 \times 10^{-8}$ m? Which hydrogen like species does this atomic number correspond to.

AS0040

41. 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.

AS0041

42. If shortest wavelength of H-atom in Balmer series is X then.

(i) What is the shortest wave length in Lyman series.

(ii) What is the longest wave length in Paschen series.

AS0042

43. Ionization energy of H-atom is 13.6 eV. If H-atoms in the ground state are excited by monochromatic light of energy 12.1 eV then the maximum number of spectral lines emitted according to Bohr's theory will be -

AS0043

44. 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.

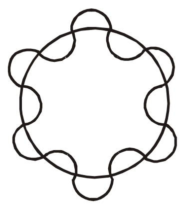
AS0044

45. 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.

AS0045

DE-BROGLIE AND HEISENBERG EQUATION

46. 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, No. of paschen lines emtted are.

AS0046

47. deBroglie wavelength associated with an electron in 4th orbit of hydrogen atom is a × (πr_0) where r_0 is radius of 1st orbit of hydrogen atom, find value of 'a'.

AS0047

48. The minimum number of waves made by a Bohr electron in an orbit of maximum magnetic quantum number 3 will be -

AS0048

49. 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.

AS0049

50. What is de Broglie wavelength (in pm) associated with an e^- accelerated through potential difference = 15 KV.

AS0050

51. To what effective potential (in volt) a proton beam be subjected to give its protons a wavelength of 1×10^{-10} m.

AS0051

52. 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 minimum uncertainity in position (in m). (Use : $\frac{h}{4\pi} = 5.2 \times 10^{-35}$)

AS0052

53. The uncertainty in the position of an electron (mass 9.1×10^{-28}gm) moving with a velocity of 3×10^{4} cm sec^{-1}, uncertainity in velocity is 0.011% will be : **(h = 6.6×10^{-34} J × s)**

AS0053

54. If uncertainities in measurement of position and momentum of an electron are equal, then the uncertainity 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.

AS0054

55. With the help of Heisenberg's uncertainty principle, show that electron can never exist in the nucleus.

AS0055

SCHRODINGER EQUATION

56. Calculate the distance of spherical nodes for '3s' orbital from nucleus?

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

AS0056

57. How many non-spherical subshell are possible that have atleast two maxima if a curve is plotted between radial probability distribution function versus radial distance for which principal quantum number : $n \leq 4$?

AS0057

58. The ratio of angular nodes of 3d orbital and radial nodes of 3p orbital is x : 1 what is the value of x.

AS0058

59. For an orbital in B^{+4} radial function is :

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

where $\sigma = \frac{Zr}{a_0}$ and $a_0 = 0.529$ Å ; Z = atomic number, r = radial distance from nucleus.

The radial node of orbital is at distance from nucleus.

AS0059

60. Tota nodes in 5f-orbital is.

AS0060

EXERCISE # S-II

1. 'α particle' of 3.6 MeV are fired towards nucleus ${}^{A}_{Z}X$, at point of closest separation distance between 'α particle' and 'X' is 1.6×10^{-14}m. Calculate atomic number of 'X'
[Given : $1/4\pi\varepsilon_0 = 9 \times 10^9$ in S.I. units]

AS0061

2. Suppose the potential energy between electron and proton at a distance r is given by $-\dfrac{ke^2}{3r^3}$. Use Bohr's theory to obtain energy of such a hypothetical atom.

AS0062

3. In the Bohr's model, for unielectronic species following symbols are used
$r_{n,z} \longrightarrow$ Radius of n^{th} orbit with atomic number "z"
$U_{n,z} \longrightarrow$ Potential energy of electron in n^{th} orbit with atomic number "z"
$K_{n,z} \longrightarrow$ Kinetic energy of electron in n^{th} orbit with atomic number "z"
$v_{n,z} \longrightarrow$ Velocity of electron in n^{th} orbit with atomic number "z"
$T_{n,z} \longrightarrow$ Time period of revolution of electron in n^{th} orbit with atomic number "z"
Calculate z in all in cases.
(i) $U_{1,2} : K_{1,z} = -8 : 1$ (ii) $r_{1,z} : r_{2,1} = 1 : 8$
(iii) $v_{1,z} : v_{3,1} = 9 : 1$ (iv) $T_{1,2} : T_{2,z} = 9 : 32$

AS0063

4. In a hypothetical H-atom the mass of electron & its charge is double of what we consider then calculate the total energy (in eV) of electron in the I^{st} orbit of such a hypothetical H-atom ?
[Assuming all others concepts and parameter to be same as we considered in Bohr's model.]

AS0064

5. In H-spectrum, longest wavelength of Lyman is 120 nm and shortest wavelength of Balmer is 360 nm. From this data, find longest wavelength of photon, that can ionize this H-atom

AS0065

6. A proton and an electron, both at rest initially, combine to form a H-atom in ground state. A single photon is emitted in this process. Find the wavelength (in nm) of this photon
(use : hc = 1237.6 ev × nm)

AS0066

7. A H-like ion is observed to emit six different wavelengths originating from all possible transitions between a group of levels. These levels have energies between –0.85 eV (Min) and –0.544 eV (Max).
(a) Find atomic number (z) of element
(b) Find quantum numbers of levels between which transitions occur.
(c) Calculate largest wavelength emitted in transitons between the levels.

AS0067

8. The angular momentum of an electron in a Bohr's orbit of H-atom is 3.1652×10^{-34} kg-m^2/sec. Calculate the wavenumber in terms of Rydberg 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]

AS0068

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.
(a) show this transition in the energy-level diagram &
(b) calculate the wavelength (in Å) of the photon.

AS0069

10. The ionisation energy of a H-like Bohr atom is 4 Rydbergs
(i) What is the wavelength (in Å) of radiation emitted when the e^- jumps from the first excited state to the ground state.
(ii) What is the radius (in cm) of first Bohr orbit for this atom. [1 Rydberg = 2.18×10^{-18} J]

AS0070

11. Photon having wavelength 12.4 nm was allowed to strike a metal plate having work function 25 eV. Calculate the
(a) Maximum kinetic energy (in eV) of photoelectrons emitted in eV.
(b) Wavelength (in Å) of electron with maximum kinetic energy in Å.
(c) Calculate the uncertainity in wavelength (in m) of emitted electron if the uncertainity in the momentum is 6.62×10^{-28} Kg m/sec.

AS0071

12. The diameter of a dust particle of mass 10^{-3} gm is 2Å. If uncertainity in speed of this particle is $\frac{3.31}{\pi}\times10^{-3}\text{m/s}$, then find minimum uncertaintity in its position

AS0072

13. 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 no. (in m^{-1}) of the light.

AS0073

14. A photon having $\lambda = 960$ Å causes the ionization of a nitrogen atom. Give the I.E. per mole of nitrogen in KJ. (Use : hc = 1240 ev × nm and $1\frac{\text{ev}}{\text{atom}} = 96.0$ kJ/mol.

AS0074

15. 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

$$\Psi_{(r)} = k_1 \cdot e^{-r/k_2} \quad (r^2 - 5k_3 r + 6k_3^2)$$

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 = No. of angular nodes

Info C = Azimuthal quantum number of subshell to orbital belongs

Info D = No. 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 $k_3 = 1$)

AS0075

EXERCISE # O-I

1. Anode rays are made up of :

(A) only protons (B) only nucleus of atom

(C) Positive residue of atoms (D) only electrons

AS0076

2. When Lithium $\left({}^{7}_{3}\text{Li}\right)$ vapours were filled in discharge tube for anode ray experiment, the anode rays were found to contain only Li^{+} ions. Thus the anode ray particle contains :

(A) 1 proton only (B) 3 proton and 4 neutron only

(C) 3 proton, 4 neutron and 2 electrons (D) 3 proton, 3 neutrons and 3 electrons

AS0077

3. The specific charge is maximum for

(A) Na^{+} (B) Al^{+3} (C) H^{+} (D) Mg^{+2}

AS0078

4. Which of the following particle is not deflected in the magnetic field

(A) Electron (B) proton (C) Neutron (D) Deuteron

AS0079

5. E/m ratio of a particle of charge 2 unit and mass 4 amu is

(A) 4.8×10^{7} C/kg (B) 0.5 C/kg (C) 4.8×10^{4} C/kg (D) 8×10^{-20} C/kg

AS0080

6. α-particles are projected towards the nucleus of following metals, with the same kinetic energy. The distance of closest approach will be minimum for which metal?

(A) Cu (B) Ag (C) Au (D) Ca

AS0081

7. Which of the following is not a conclusion of Rutherford's atomic model -

(A) Most of the part inside an atom is empty

(B) Almost all mass of an atom is concentrated in the nucleus.

(C) The size of nucleus is very small in compartison to the size of atom

(D) Electron revolves around the nucleus in definite orbits.

AS0082

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

(A) α-particle (B) proton (C) dueteron (D) neutron

AS0083

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

AS0084

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

AS0085

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

AS0086

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

AS0087

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

AS0088

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

AS0089

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

AS0090

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

AS0091

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

AS0092

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

AS0093

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

AS0094

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

AS0095

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

AS0096

22. If the radius of 3rd Bohr's orbit of H is x, then radius of 4th orbit of Li^{2+} ion would be :-
(A) $\frac{27}{16}x$ (B) $\frac{16}{27}x$ (C) $\frac{9}{16}$ (D) None of these

AS0097

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

AS0098

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

AS0099

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

AS0100

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

AS0101

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

AS0102

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

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

AS0103

29. Angular momentum for P–shell electron :–

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

AS0104

30. Angular momentum in 2^{nd} Bohr orbit of H-atom is x. Then find out angular momentum in Ist excitetd state of Li^{+2} :–

(A) 3x (B) 9x (C) x/2 (D) x

AS0105

31. The orbit from which when electron will jump in other orbit, energy may be absorbed but not emitted out, will be

(A) 1st orbit (B) 2nd orbit (C) 7th orbit (D) infinite orbit

AS0106

32. The potential energy of electron revolving in the ground state of H-atom is

(A) -13.6 eV (B) -6.8 eV (C) -27.2 eV (D) Zero

AS0107

33. If the potential energy (PE) of hydrogen electron is –3.02eV then in which of the following excited level is electron present :-

(A) 1^{st} (B) 2^{nd} (C) 3^{rd} (D) 4^{th}

AS0108

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

(A) 4.5 eV (B) 8.53 eV (C) 25 eV (D) 16.53 eV

AS0109

35. A photon of energy 12.75 ev is completely absorbed by a hydrogen atom initially in ground state. The principle quantum number of the excited state is

(A) 1 (B) 3 (C) 4 (D) ∞

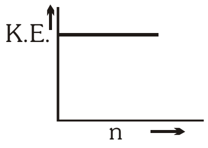
AS0110

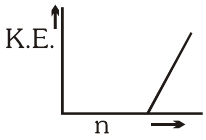
36. An hydrogen atom (ionisation energy 13.6 eV) jumps from third excited state to first excited state. The energy of photon emitted in the process is

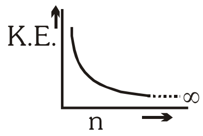
(A) 1.89 eV (B) 2.55 eV (C) 12.09 eV (D) 12.75 eV

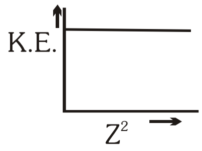
AS0111

37. Which is correct graph :-

(A) 

(B) 

(C) 

(D) 

AS0112

38. The energy required to remove an electron from the surface of sodium metal is 3.3 eV. What is the longest wavelength of radiation with which it can show photoelectric effect?
Use $h = 6.6 \times 10^{-34}$ J.s

(A) 1.75×10^{-7} m (B) 3.75×10^{-5} m (C) 1.75×10^{-5} m (D) 3.75×10^{-7} m

AS0113

39. Which is correct for any H like species :-

(A) $(E_2 - E_1) > (E_3 - E_2) > (E_4 - E_3)$
(B) $(E_2 - E_1) < (E_3 - E_2) < (E_4 - E_3)$
(C) $(E_2 - E_1) = (E_3 - E_2) = (E_4 - E_3)$
(D) $(E_2 - E_1) = 1/4\ (E_3 - E_2) = 1/9\ (E_4 - E_3)$

AS0114

40. A single electron orbits a stationary nucleus of charge +Ze, where Z is a constant. It requires 47.2 eV to excite electron from second Bohr orbit to third Bohr orbit, find the value of Z :-

(A) 1 (B) 3 (C) 5 (D) 4

AS0115

41. The energy of H–atom in nth orbit is E_n then energy in nth orbit of singly ionised helium atom will be:

(A) $4E_n$ (B) $E_n/4$ (C) $2E_n$ (D) $E_n/2$

AS0116

42. Which electronic level would allow the hydrogen atom to absorb a photon but not to emit a photon

(A) 3s (B) 2p (C) 2s (D) 1s

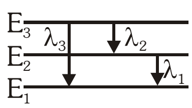
AS0117

43. The third line in Balmer series corresponds to an electronic transition between which Bohr's orbits in hydrogen

(A) $5 \rightarrow 3$ (B) $5 \rightarrow 2$ (C) $4 \rightarrow 3$ (D) $4 \rightarrow 2$

AS0118

44. In the following transition which statement is correct



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

AS0119

45. The first Lyman transition in the hydrogen spectrum has $\Delta E = 10.2$ eV. The same energy change is observed in the second Balmer transition of :-

(A) Li^{2+} (B) Li^{+} (C) He^{+} (D) Be^{3+}

AS0120

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

(A) 6 (B) 10 (C) 4 (D) 0

AS0121

47. What is the shortest wavelength in the Pfund series of He^{+} ion :-

(A) $\frac{25}{R}$ (B) $\frac{4}{R}$ (C) $\frac{4R}{25}$ (D) $\frac{25}{4R}$

AS0122

48. The shortest wavelength of He^{+} ion in Balmer series is x, then longest wavelength in the Paschene series of Li^{+2} is

(A) $\frac{36x}{5}$ (B) $\frac{16x}{7}$ (C) $\frac{9x}{5}$ (D) $\frac{5x}{9}$

AS0123

49. The ratio of wave length of photon corresponding to the α-line of Lyman series in H-atom and β-line of Balmer series in He^{+} is

(A) 1 : 1 (B) 1 : 2 (C) 1 : 4 (D) 3 : 16

AS0124

50. Three energy levels P, Q, R of a certain atom are such that $E_P < E_Q < E_R$. If λ_1, λ_2 and λ_3 are the wave length of radiation corresponding to transition $R \rightarrow Q$; $Q \rightarrow P$ and $R \rightarrow P$ respectively. The correct relationship between λ_1, λ_2 and λ_3 is

(A) $\lambda_1 + \lambda_2 = \lambda_3$ (B) $\frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$ (C) $\lambda_3 = \sqrt{\lambda_1 \lambda_2}$ (D) $\frac{2}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$

AS0125

51. Number of possible spectral lines which may be emitted in bracket series in H atom, if electrons present in 9^{th} excited level returns to ground level, are

(A) 21 (B) 6 (C) 45 (D) 5

AS0126

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

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

AS0127

53. An electron, a proton and an alpha particle have kinetic energies of 16E, 4E and E respectively. What is the qualitative order of their de Broglie wavelengths?

(A) $\lambda_e > \lambda_p = \lambda_\alpha$ (B) $\lambda_p = \lambda_\alpha > \lambda_e$ (C) $\lambda_p > \lambda_e > \lambda_\alpha$ (D) $\lambda_\alpha < \lambda_e$ » λ_p

AS0128

54. The wavelength associated with a golf weighing 200g and moving at a speed of 5m/h is of the order

(A) 10^{-10}m (B) 10^{-20}m (C) 10^{-30}m (D) 10^{-40}m

AS0129

55. An electron has kinetic energy 2.8×10^{-23} J. de-Broglie wavelength will be nearly :-
($m_e = 9.1 \times 10^{-31}$ kg)

(A) 9.28×10^{-24} m (B) 9.28×10^{-7} m (C) 9.28×10^{-8} m (D) 9.28×10^{-10} m

AS0130

56. What will be de-Broglie wavelength of an electron moving with a velocity of 1.2×10^5 ms^{-1}:-

(A) 6.068×10^{-9} m (B) 3.133×10^{-37} m (C) 6.626×10^{-9} m (D) 6.018×10^{-7} m

AS0131

57. For a valid Bohr orbit, its circumfrence should be:

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

AS0132

58. The number of waves made by a Bohr electron in an orbit of maximum magnetic quantum number + 2 :

(A) 3 (B) 4 (C) 2 (D) 1

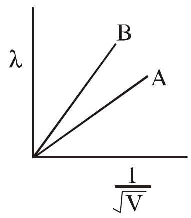
AS0133

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

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

AS0134

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



(A) $M_A = M_B$

(B) $M_A > M_B$

(C) $M_A < M_B$

(D) $M_A \leq M_B$

AS0135

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

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

AS0136

62. Which quantum number is not related with Schrodinger equation

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

AS0137

63. Which is true about ψ :-

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

(B) ψ represent the amplitude of the electron wave

(C) Both A and B

(D) None of these

AS0138

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

(A) Particles only (B) Wave only

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

AS0139

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

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

AS0140

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

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

AS0141

67. Which orbitlal has two angular nodal planes :-

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

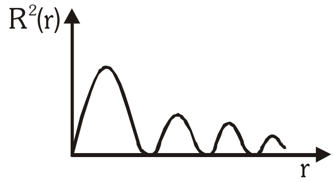
AS0142

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

Observation 1 : x y plane acts as nodal plane

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

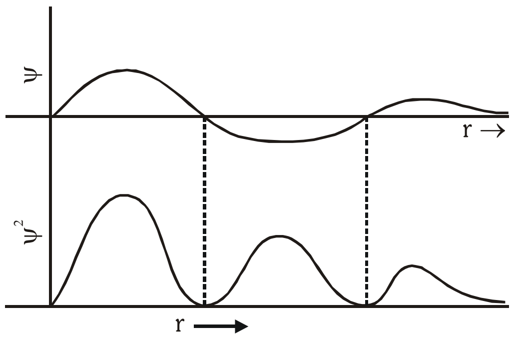
Observation 3 : $R^2(r)$ v/s r curve is obtained for the orbital is



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

AS0143

69. The wave function ψ vs radial distance (r) and square of wave function $(\psi)^2$ vs radial distance (r) graph of certain orbital is given. Identify the orbital.



(A) 3s (B) 4d (C) 3p (D) 4p

AS0144

70. The distance of spherical nodes from nucleus for the given orbital are

$$\psi_{\text{radial}} = \frac{1}{9\sqrt{2}}\left(\frac{Z}{a_0}\right)^{3/2}[\sigma^2 - 4\sigma + 3]\ \exp\ (-\sigma/2)$$

where a_0 & Z are the constants and $\sigma = \frac{2Zr}{a_0}$

(A) Zero, infinity (B) $\frac{a_0}{Z}, \frac{1}{2}\frac{a_0}{Z}$ (C) $\frac{3}{2}\frac{a_0}{Z}, \frac{1}{2}\frac{a_0}{Z}$ (D) $\frac{a_0}{Z}, \frac{3}{2}\frac{a_0}{Z}$

AS0145

71. The radial funtion for an orbitals is :

$$R(r) = \frac{1}{9\sqrt{6}}\left(\frac{1}{a_0}\right).(4-\sigma)\ \sigma e^{-\frac{6}{3}};\sigma = \frac{r}{a_0}.$$

Pick out the incorrect statement :

(A) orbital must be 3p

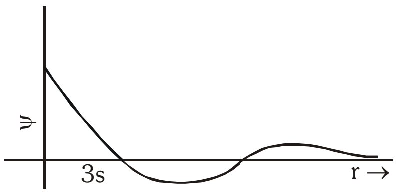
(B) orbital must be $3p_x$

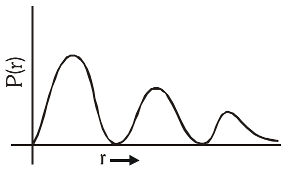
(C) the orbital has one radial node

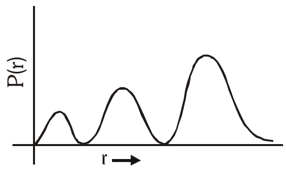
(D) the orbital must have one angular node

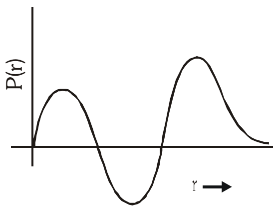
AS0146

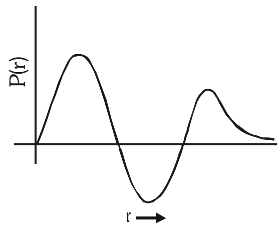
72. The wave function (ψ) verses radial distance (r) curve for certain orbital is given. Predict the shape of $\psi^2.4\pi r^2$ (radial probability distribution function) verses r graph.



(A) 

(B) 

(C) 

(D) 

AS0147

EXERCISE # O-II

SINGLE CORRECT :

1. In a hydrogen like sample electron is in 2^{nd} excited state, the energy of 4^{th} state of this sample is -13.6 eV, then incorrect statement is :

(A) Atomic number of element is 4.

(B) 3 different types of spectral line will be observed if electrons make transition upto ground state from the 2^{nd} excited state.

(C) A 25 eV photon can set free the electron from the 2^{nd} excited state of this sample

(D) 2^{nd} line of Balmer series of this sample has same energy value as 1^{st} excitation energy of H-atoms.

AS0148

2. 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) 3.32×10^{-10} m (B) 1.17 Å (C) 2.32×10^{-9} nm (D) 3.33 pm

AS0149

3. Given ΔH for the process $Li(g) \longrightarrow Li^{+3}(g) + 3e^-$ 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

AS0150

4. Consider the following nuclear reactions involving X & Y.

$$X \longrightarrow Y + {}^{4}_{2}He$$

$$Y \longrightarrow {}_{8}O^{18} + {}_{1}H^{1}$$

If both neutrons as well as protons in both the sides are conserved in nuclear reaction then moles of neutrons in 4.6 gm of X

(A) 2.4 N_A (B) 2.4 (C) 4.6 (D) 0.2 N_A

AS0151

Assertion and Reason :

5. **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 1^{st} & 2^{nd} 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.

AS0152

6. **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 : Balmer series radiations belong to visible range in all H-atoms.

(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.

AS0153

More than one may be correct :

7. Which of the following could be derived from Rutherford's α-particle scattering experiment-

(A) Most of the space in the atom is empty

(B) The radius of the atom is about 10^{-10} m while that of nucleus is 10^{-15}m

(C) Electrons move in a circular path of fixed energy called orbits

(D) Electrons and the nucleus are held together by electrostatic forces of attraction.

AS0154

8. In a H-like sample electrons make transition from 5^{th} excited state to 2^{nd} excited state

(A) 10 different spectral lines will be emiited

(B) 6 different spectral lines will be emiited

(C) Number of lines belonging to Balmer series will be 4

(D) Number of lines belonging to paschen series will be 3

AS0155

9. The kinetic energy of photoelectron emitted on irradiating a metal surface with frequency υ is related by KE = hv – ϕ. The plots of KE vs. incidented frequency v 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.

AS0156

10. Select the correct statement(s):

(A) All electromagnetic radiation travel with speed of light in vaccum.

(B) Energy of photon of UV light is lower than that of yellow light.

(C) He^{+} and H have identical spectrum.

(D) The total energy of an electron in unielectronic specie is greater than zero

AS0157

11. Choose the incorrect statement(s):

(A) Increasing order of wavelength is

Micro waves > Radio waves > IR waves > visible waves > UV waves

(B) The order of Bohr radius is (r_n : where n is orbit number for a given atom) $r_1 < r_2 < r_3 < r_4$

(C) The order of total energy is (E_n : where n is orbit number for a given atom) $E_1 > E_2 > E_3 > E_4$

(D) The order of velocity of electron in H, He^+, Li^+, Be^{3+} species in second Bohr orbit is

$Be^{3+} > Li^{+2} > He^+ > H$

AS0158

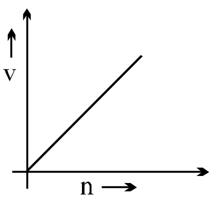
12. Select the correct curve(s):

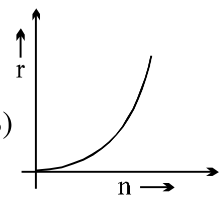
If v = velocity of electron in Bohr's orbit

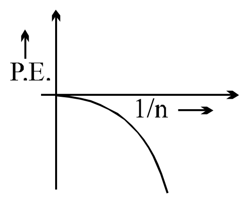
r = Radius of electron in Bohr's orbit

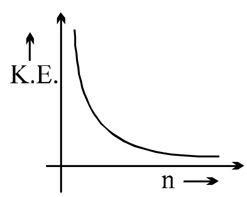
P.E. = Potential energy of electron in Bohr's orbit

K.E. = Kinetic energy of electron in Bohr's orbit.

(A) 

(B) 

(C) 

(D) 

AS0159

13. Which is / are correct statement.

(A) The difference in angular momentum associated with the electron present in consecutive orbits of H-atom is $(n-1)\dfrac{h}{2\pi}$.

(B) Energy difference between energy levels will be changed if, P.E. at infinity assigned value other than zero.

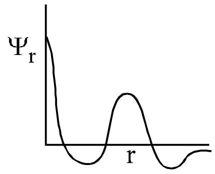
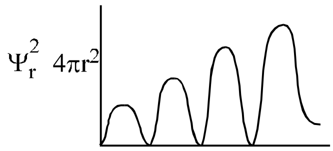
(C) Frequency of spectral line in a H-atom is in the order of $(2 \rightarrow 1) < (3 \rightarrow 1) < (4 \rightarrow 1)$.

(D) On moving away from the nucleus, kinetic energy of electron decreases.

AS0160

Match the column :

14. Column I & Column II contain data on Schrondinger 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)	atleast one angular node is present	(S)	$6d_{xy}$

AS0161

15.

	Column-I		**Column-II**
(A)	Electron moving in 2^{nd} orbit in He^+ ion electron is	(P)	Radius of orbit in which moving is 0.529 Å
(B)	Electron moving in 3^{rd} orbit in H-atom	(Q)	Total energy of electron is $(-)13.6 \times 9$eV
(C)	Electron moving in 1^{st} orbit in Li^{+2} ion	(R)	Velocity of electron is $\frac{2.188 \times 10^6}{3}$ m/sec
(D)	Electron moving in 2^{nd} orbit is Be^{+3} ion	(S)	De-broglie wavelength of electron is $\sqrt{\frac{150}{13.6}}$ Å

AS0162

COMPREHENSION :

Question No. 16 to 18 (3 questions)

The French physicist Louis de Broglie in 1924 postulated that matter, like radiation, should exhibit a dual behaviour. 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 decreases 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 Δ(mv) must be greater than or equal to $\frac{h}{4\pi}$. i.e.

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

16. The correct order of wavelength of Hydrogen ($_1H^1$), Deuterium ($_1H^2$) and Tritium ($_1H^3$) moving with same kinetic energy is

(A) $\lambda_H > \lambda_D > \lambda_T$ (B) $\lambda_H = \lambda_D = \lambda_T$ (C) $\lambda_H < \lambda_D < \lambda_T$ (D) $\lambda_H < \lambda_D > \lambda_T$

AS0163

17. 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) $1 \rightarrow 2$

AS0164

18. If the uncertainty in velocity & position is same, then the uncertainty in momentum will be

(A) $\sqrt{\frac{hm}{4\pi}}$ (B) $m\sqrt{\frac{h}{4\pi}}$ (C) $\sqrt{\frac{h}{4\pi m}}$ (D) $\frac{1}{m}\sqrt{\frac{h}{4\pi}}$

AS0165

Question No. 19 to 22 (4 questions)

The only electron in the hydrogen atom resides under ordinary conditions on the first orbit. When energy is supplied, the electron moves to higher energy orbit depending on the amount of energy absorbed. When this electron returns to any of the lower orbits, it emits energy. Lyman series is formed when the electron returns to the lowest orbit while Balmer series is formed when the electron returns to second orbit. Similarly, Paschen, Brackett and Pfund series are formed when electron returns to the third, fourth and fifth orbits from higher energy orbits respectively.

Maximum number of lines produced when an electron jumps from nth level to ground level is equal to $\frac{n(n-1)}{2}$. For example, in the case of $n = 4$, number of lines produced is 6. ($4 \to 3$, $4 \to 2$, $4 \to 1$, $3 \to 2$, $3 \to 1$, $2 \to 1$). When an electron returns from n_2 to n_1 state, the number of lines in the spectrum will be equal to

$$\frac{(n_2 - n_1)(n_2 - n_1 + 1)}{2}$$

If the electron comes back from energy level having energy E_2 to energy level having energy E_1, then the difference may be expressed in terms of energy of photon as:

$$E_2 - E_1 = \Delta E \, , \, \lambda = \frac{hc}{\Delta E}$$

Since h and c are constants, ΔE corresponds to definite energy; thus each transition from one energy level to another will produce a light of definite wavelength. This is actually observed as a line in the spectrum of hydrogen atom.

Wave number of line is given by the formula $\bar{\nu} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$.

where R is a Rydberg's constant ($R = 1.1 \times 10^7 \text{ m}^{-1}$)

19. The energy photon emitted corresponding to transition n = 3 to n = 1 is [$h = 6 \times 10^{-34}$ J-sec.]

(A) 1.76×10^{-18} J (B) 1.98×10^{-18} J (C) 1.76×10^{-17} J (D) None of these

AS0166

20. In a collection of H-atom, electrons make transition from 5th excited state to 2nd excited state then maximum number of different types of photons observed are

(A) 3 (B) 4 (C) 6 (D) 15

AS0167

21. The difference in the wavelength of the 1st line of Lyman series and 2nd line of Balmer series in a hydrogen atom is

(A) $\frac{9}{2R}$ (B) $\frac{4}{R}$ (C) $\frac{88}{15R}$ (D) None

AS0168

22. The wave number of electromagnetic radiation emitted during the transition of electron in between two levels of Li^{2+} ion whose principal quantum numbers sum is 4 and difference is 2 is

(A) 3.5 R (B) 4 R (C) 8 R (D) $\frac{8}{9}R$

AS0169

1 TABLE (3Q)

	Column-I		Column-II		Column-III
(A)	Energy of electron in H-like atomic orbital	(P)	Principal quantum number(n)	(I)	Radial function [R(r)]
(B)	Orientation and shape of H-like atomic orbital	(Q)	Azimuthal quantum number (l)	(II)	Angular function
(C)	Magnitude & direction of spin angular momentum	(R)	Magnetic quantum number (m)	(III)	Wave function [Ψ]
(D)	Probability density of electron in s-orbital of H-like atom/ion	(S)	Spin quantum number(s)	(IV)	Cannot be determined from Schrodinger equation

Assume no external electric or magnetic fields in Q.23 to Q.25

23. Which of the following option is incorrectly matched -

(A) B – Q – II (B) B – R – II (C) B – P – I (D) B – Q – III

AS0170

24. Which option is correctly matched ?

(A) C – S – III (B) D – R – III (C) A – P – IV (D) C – S – IV

AS0170

25. If option (A) is considered in presence of external electric or magnetic field then which option is incorrect -

(A) A – P – III (B) A – Q – III (C) A – R – III (D) A – S – I

AS0170

EXERCISE # J-MAINS

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

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

AS0171

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

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

AS0172

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

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

AS0173

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

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

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

AS0174

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

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

AS0175

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

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

AS0176

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

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

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

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

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

AS0177

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

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

AS0178

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9. Ionization energy of gaseous Na atoms is 495.5 $kjmol^{-1}$. The lowest possible frequency of light that ionizes a sodium atom is

($h = 6.626 \times 10^{-34}$ Js, $N_A = 6.022 \times 10^{23}$ mol^{-1}) **[JEE-Main(online) 2014]**

(1) 3.15×10^{15} s^{-1} (2) 4.76×10^{14} s^{-1} (3) 1.24×10^{15} s^{-1} (4) 7.50×10^{4} s^{-1}

AS0179

10. Which of the following is the energy of a possible excited state of hydrogen?

[JEE-Main(offline) 2015]

(1) –3.4 eV (2) +6.8 eV (3) +13.6 eV (4) –6.8 eV

AS0180

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

(1) Visible photon > Thermal electron > Thermal neutron

(2)Thermal proton > Thermal electron > Visible photon

(3)Visible photon > Thermal neutron > Thermal electron

(4) Thermal proton > Visible photon > Thermal electron

AS0181

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

(1) $\sqrt{2meV}$ (2) meV (3) 2meV (4) $\sqrt{meV}$

AS0182

13. The radius of the second Bohr orbit for hydrogen atom is : **[JEE-Main(offline) 2017]**

(Plank's const. $h = 6.6262 \times 10^{-34}$ Js ; mass of electron = 9.1091×10^{-31} kg ; charge of electron $e = 1.60210 \times 10^{-19}$ C ; permittivity of vaccum

$\epsilon_0 = 8.854185 \times 10^{-12}$ kg^{-1} m^{-3} A^2)

(1) 1.65Å (2) 4.76Å (3) 0.529Å (4) 2.12Å

AS0183

14. If the shortest wavelength in Lyman series of hydrogen atom is A, then the longest wavelength in Paschen series of He^+ is : **[JEE-Main(online) 2017]**

(1) $\frac{36A}{5}$ (2) $\frac{9A}{5}$ (3) $\frac{36A}{7}$ (4) $\frac{5A}{9}$

AS0184

15. The electron in the hydrogen atom undergoes transition from higher orbitals to orbital of radius 211.6 pm. This transition is associated with:- **[JEE-Main(online) 2017]**

(1) Brackett series (2) Balmer series (3) Lyman series (4) Paschen series

AS0185

16. The de-Broglie's wavelength of electron present in first Bohr orbit of 'H' atom is :- **[JEE-Main(online) 2018]**

(1) $\frac{0.529}{2\pi}$Å (2) $2\pi \times 0.529$Å (3) 0.529Å (4) 4×0.529Å

AS0186

17. Ejection of the photoelectron from metal in the photoelectric effect experiment can be stopped by applying 0.5 V when the radiation of 250 nm is used. The work function of the metal is :

(1) 5 eV (2) 4 eV (3) 5.5 eV (4) 4.5 eV **[JEE-Main(online) 2018]**

AS0187

18. Which of the following statements is false ? **[JEE-Main(online) 2018]**

(1) Photon has momentum as well as wavelength.

(2) Splitting of spectral lines in electrical field is called Stark effect.

(3) Frequency of emitted radiation from a black body goes from a lower wavelength to higher wavelength as the temperature increases.

(4) Rydberg constant has unit of energy.

AS0188

19. If p is the momentum of the fastest electron ejected from a metal surface after the irradiation of light having wavelength λ, then for 1.5 p momentum of the photoelectron, the wavelength of the light should be: **[JEE-Main(online) 2019]**

(Assume kinetic energy of ejected photoelectron to be very high in comparison to work function)

(1) $\frac{1}{2}\lambda$ (2) $\frac{3}{4}\lambda$ (3) $\frac{2}{3}\lambda$ (4) $\frac{4}{9}\lambda$

AS0189

20. The quantum number of four electrons are given below - **[JEE-Main(online) 2019]**

I. $n = 4, l = 2, m_l = -2, m_s = -\frac{1}{2}$

II. $n = 3, l = 2, m_l = 1, m_s = +\frac{1}{2}$

III. $n = 4, l = 1, m_l = 0, m_s = +\frac{1}{2}$

IV. $n = 3, l = 1, m_l = 1, m_s = -\frac{1}{2}$

The correct order of their increasing energies will be -

(1) IV < III < II < I (2) IV < II < III < I (3) I < II < III < IV (4) I < III < II < IV

AS0190

21. For any given series of spectral lines of atomic hydrogen, let $\Delta\bar{v} = \bar{v}_{max} - \bar{v}_{min}$ be the difference in maximum and minimum frequencies in cm^{-1}. The ratio $\Delta\bar{v}_{Lyman} / \Delta\bar{v}_{Balmer}$ is :

(1) 27 : 5 (2) 4 : 1 **[JEE-Main(online) 2019]**

(3) 5 : 4 (4) 9 : 4

AS0191

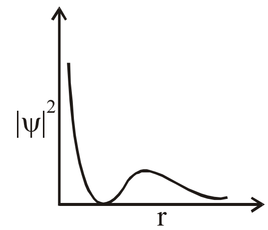
22. The ratio of the shortest wavelength of two spectral series of hydrogen spectrum is found to be about 9. The spectral series are: **[JEE-Main(online) 2019]**

(1) Paschen and P fund (2) Lyman and Paschen

(3) Brackett and Piund (4) Balmer and Brackett

AS0192

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



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

(3) 2p orbital (4) 2s orbital

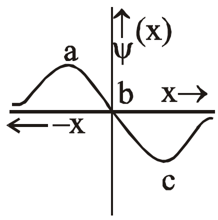
AS0193

24. Among the following, the energy of 2s orbital is lowest in : **[JEE-Main(online) 2019]**

(1) K (2) Na (3) Li (4) H

AS0194

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



(1) in the region a and b (2) in the region a and c

(3) only in the region c (4) only in the region a

AS0195

26. What is the work function of the metal if the light of wavelength 4000 Å generates photoelectrons of velocity 6×10^5 ms^{-1} form it ? **[JEE-Main(online) 2019]**

(Mass of electron = 9×10^{-31} kg

Velocity of light = 3×10^8 ms^{-1}

Planck's constant = 6.626×10^{-34} Js

Charge of electron = 1.6×10^{-19} JeV^{-1})

(1) 0.9 eV (2) 4.0 eV (3) 2.1 eV (4) 3.1 eV

AS0196

27. If the de Broglie wavelength of the electron in nth Bohr orbit in a hydrogenic atom is equal to 1.5 πa_0(a_0 is Bohr radius), then the value of n/z is : **[JEE-Main(online) 2019]**

(1) 1.0 (2) 0.75 (3) 0.40 (4) 1.50

AS0197

28. The upper stratosphere consisting of the ozone layer protects us from the sun's radiation that falls in the wavelength region of : **[JEE-Main(online) 2019]**

(1) 600-750 nm (2) 0.8-1.5 nm (3) 400-550 nm (4) 200-315 nm

AS0198

29. Heat treatment of muscular pain involves radiation of wavelength of about 900 nm. Which spectral line of H-atom is suitable for this purpose ? **[JEE-Main(online) 2019]**

[$R_H = 1 \times 10^5\ cm^{-1}$, $h = 6.6 \times 10^{-34}$ Js, $c = 3 \times 10^8\ ms^{-1}$]

(1) Paschen, $5 \rightarrow 3$ (2) Paschen, $\infty \rightarrow 3$ (3) Lyman, $\infty \rightarrow 1$ (4) Balmer, $\infty \rightarrow 2$

AS0199

30. The de Broglie wavelength (λ) associated with a photoelectron varies with the frequency (v) of the incident radiation as, [v_0 is thershold frequency] : **[JEE-Main(online) 2019]**

(1) $\lambda \propto \frac{1}{(v-v_0)^{\frac{3}{2}}}$ (2) $\lambda \propto \frac{1}{(v-v_0)^{\frac{1}{2}}}$ (3) $\lambda \propto \frac{1}{(v-v_0)^{\frac{1}{4}}}$ (4) $\lambda \propto \frac{1}{(v-v_0)}$

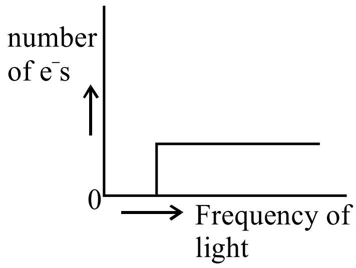
AS0200

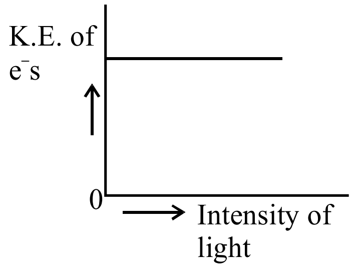
31. The ground state energy of hydrogen atom is –13.6 eV. The energy of second excited state He^+ ion in eV is : **[JEE-Main(online) 2019]**

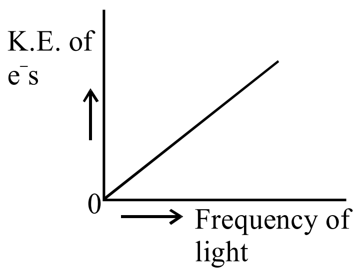
(1) –6.04 (2) –27.2 (3) –54.4 (4) –3.4

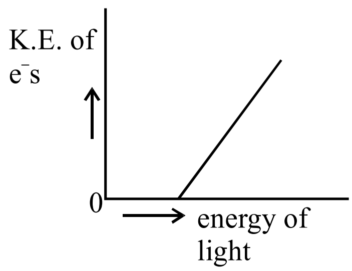
AS0201

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

(1)


(2)


(3)


(4)


AS0202

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

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

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

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

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

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

AS0203

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

(1) Linear with slope - R_H **[JEE-Main(online) 2019]**

(2) Linear with intercept - R_H

(3) Non linear

(4) Linear with slope R_H

AS0204

35. The number of orbitals associated with quantum numbers n = 5, $m_s = +\frac{1}{2}$ is :

[JEE-Main(online) 2020]

(1) 11 (2) 25 (3) 15 (4) 50

AS0205

36. For the Balmer series in the spectrum of H atom, $\bar{v} = R_H\left\{\frac{1}{n_1^2} - \frac{1}{n_2^2}\right\}$, the correct statements among (I) and (IV) are : **[JEE-Main(online) 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

(1) (II), (III), (IV) (2) (I), (II), (III) (3) (I), (III), (IV) (4) (I), (II), (IV)

AS0206

37. The radius of the second Bohr orbit, in terms of the Bohr radius, a_0, in Li^{2+} is :

[JEE-Main(online) 2020]

(1) $\frac{4a_0}{9}$ (2) $\frac{2a_0}{9}$ (3) $\frac{2a_0}{3}$ (4) $\frac{4a_0}{3}$

AS0207

38. The de Broglie wavelength of an electron in the 4^{th} Bohr orbit is : **[JEE-Main(online) 2020]**

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

AS0208

EXERCISE # J-ADVANCED

Paragraph for questions 1 to 3

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

1. The state S_1 is :-

(A) 1s (B) 2s (C) 2p (D) 3s

AS0209

2. Energy of the state S_1 in units of the hydrogen atom ground state energy is :-

(A) 0.75 (B) 1.50 (C) 2.25 (D) 4.50

AS0210

3. The orbital angular momentum quantum number of the state S_2 is :-

(A) 0 (B) 1 (C) 2 (D) 3

AS0211

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

AS0212

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

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

AS0213

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

(A) $\frac{h^2}{4\pi^2 ma_0^2}$ (B) $\frac{h^2}{16\pi^2 ma_0^2}$ (C) $\frac{h^2}{32\pi^2 ma_0^2}$ (D) $\frac{h^2}{32\pi^2 ma_0^2}$

AS0214

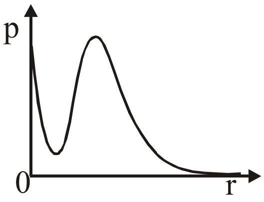
7. The atomic masses of He and Ne are 4 and 20 a.m.u. respectively. The value of the de Broglie wavelength of He gas at –73 ºC is "M" times that of the de Broglie wavelength of Ne at 727 ºC. M is. **[JEE 2013]**

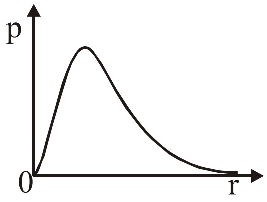
AS0215

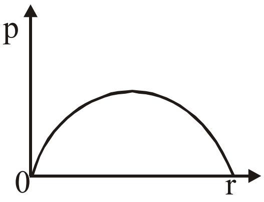
8. In an atom, the total number of electrons having quantum numbers n = 4, $|m_\ell| = 1$ and $m_s = -\frac{1}{2}$ is **[JEE 2014]**

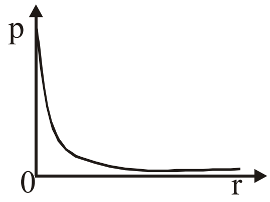
AS0216

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

(A)


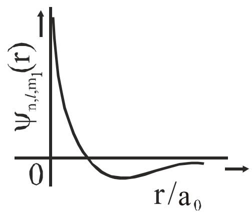
(B)


(C)


(D)


AS0217

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

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

10. For the given orbital in column 1, the only **CORRECT** combination for any hydrogen - like species is :

(A) (IV) (iv) (R) (B) (II) (ii) (P) (C) (III) (iii) (P) (D) (I) (ii) (S)

AS0218

11. For He^+ ion, the only **INCORRECT** combination is

(A) (II) (ii) (Q) (B) (I) (i) (S) (C) (I) (i) (R) (D) (I) (iii) (R)

AS0219

12. For hydrogen atom, the only **CORRECT** combination is

(A) (I) (iv) (R) (B) (I) (i) (P) (C) (II) (i) (Q) (D) (I) (i) (S)

AS0220

13. The ground state energy of hydrogen atom is –13.6 eV. Consider an electronic state Ψ of He^+ whose energy, azimuthal quantum number and magnetic quantum number are –3.4 eV, 2 and 0 respectively. Which of the following statement(s) is(are) true for the state Ψ? **[JEE 2019]**

(1) It has 2 angular nodes

(2) It has 3 radial nodes

(3) It is a 4d state

(4) The nuclear charge experienced by the electron in this state is less than 2e, where e is the magnitude of the electronic charge.

AS0221

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

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

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

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

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

AS0222

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

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

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

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

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

AS0223

ANSWER KEY

EXERCISE # S-I

1. Ans.(1 : 1)
2. Ans.(4 : 9)
3. Ans. n < α < p < e
4. Ans.6.0 × 10^{-19} unit.
5. Ans.1.6 × 10^{-19} Coulomb.
6. Ans.8 × 10^{-15} : 1
7. Ans.2.3 × 10^{17} kg/m^3
8. Ans.1 : 2
9. Ans.1.28 × 10^{-14} m.
10. Ans.1.44 × 10^{7} m/s
11. Ans.1500 Å
12. Ans.150 KHz
13. Ans.1 : 5
14. Ans.7.5 × 10^{12} Hz
15. Ans.4.96 × 10^{-19} Joule
16. Ans.1.0 × 10^{5}
17. Ans.10^{22}
18. Ans.0.5
19. Ans.6200 Å
20. Ans.3 × 10^{22}
21. Ans.(2 × 10^{15} Hz , 1.5 × 10^{-7} m)
22. Ans. (1)
23. Ans.50 %
24. Ans.3.06 V
25. Ans. 0.41375 eV
26. Ans.(0.2645) Å
27. Ans.(x = 4)
28. Ans.5.44 × 10^{5} m/s
29. Ans. 2

30 Ans.8×10^{6}

31. Ans. 6530×10^{12}Hz
32. Ans. – 1.36 × 10^{-19} Joules
33. h/π
34. Ans.(2)
35. Ans. 1.18 × 10^{7}
36. Ans.(– 217.9 × 10^{-20} J)

37 Ans. 340 ev , – 680 eV

38 Ans.(6)

39. Ans.6563 Å ; 1216 Å ; 1026 Å
40. Ans.10.2 eV , z = 2
41. Ans.113.74 Å
42. Ans. (i) $\frac{x}{4}$; (ii) $\frac{36x}{7}$

43 Ans.(3)

44 Ans. (4)

45 Ans.3.09 × 10^{8} cm/sec

46. Ans(3)
47. Ans (8)
48. Ans.(4)
49. Ans.3.68 × 10^{-65} m

50 Ans.10 pm

51. Ans.0.0826 volts
52. Ans.1.05×10^{-13} m

53. Ans.(0.175 cm)

54. Ans (8)

56 $\frac{9+3\sqrt{3}}{2}a_0, \frac{9-3\sqrt{3}}{2}a_0$

57 Ans.(3)

58. Ans.(2)

59. Ans.(0.423 Å)

60. Ans.(4)

EXERCISE # S-II

1. Ans. 20

2. Ans. $E = \frac{n^6 h^6}{384\ m^3\ K^2\ e^4\ \pi^6}$

3. Ans. (i) 1, (ii) 2, (iii) 3, (iv) 3

4. Ans. – 435.2 eV

5. Ans. 90 nm

6. Ans. 91 nm

7. Ans. (a) Z = 3 ; (b) $n_1 = 12$, $n_2 = 15$; (c) $\lambda_{max} = 15406$ nm

8. Ans. $R\left(\frac{8}{9}\right)$

9. Ans. 973.5 Å

10. Ans. 303.89 Å , 2.645×10^{-9} cm

11. Ans. (a) 75 eV;(b) 1.414 Å;(c) 2×10^{-14} m

12. Ans. 5×10^{-26} m

13. Ans. $3.63 \times 10^6\ m^{-1}$

14. Ans. 1240 kJ/mol.

15. Ans. 300303

EXERCISE # O-I

1. Ans.(C)	2. Ans.(C)	3. Ans.(C)	4. Ans.(C)
5. Ans.(A)	6. Ans.(D)	7. Ans.(D)	8. Ans.(D)
9. Ans.(D)	10. Ans.(C)	11. Ans.(A)	12. Ans.(D)
13. Ans.(B)	14. Ans.(B)	15. Ans.(B)	16. Ans.(B)
17. Ans.(B)	18. Ans.(C)	19. Ans.(A)	20. Ans.(C)
21. Ans.(A)	22. Ans.(B)	23. Ans.(A)	24. Ans.(B)
25. Ans.(B)	26. Ans.(A)	27. Ans.(C)	28. Ans.(C)
29. Ans.(A)	30. Ans.(D)	31. Ans.(A)	32. Ans.(C)
33. Ans.(B)	34. Ans.(D)	35. Ans.(C)	
36. Ans.(B)	37. Ans.(C)	38. Ans.(D)	39. Ans.(A)
40. Ans.(C)	41. Ans.(A)	42 Ans.(D)	43. Ans.(B)
44. Ans.(C)	45. Ans.(C)	46. Ans.(A)	47. Ans.(D)
48. Ans.(B)	49. Ans.(A)	50. Ans.(B)	51. Ans.(B)
52. Ans.(C)	53. Ans.(A)	54. Ans.(C)	55. Ans.(C)
56. Ans.(A)	57. Ans.(A)	58. Ans.(A)	59. Ans.(B)
60 Ans.(B)	61. Ans.(C)	62 Ans.(D)	63. Ans.(B)
64. Ans.(C)	65. Ans.(B)	66. Ans.(C)	67. Ans.(C)
68. Ans.(D)	69. Ans.(D)	70. Ans.(C)	71. Ans.(B)
72. Ans.(B)			

EXERCISE # O-II

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

14. Ans.(A) P, (B) P,Q,S, (C) P, R (D) Q, S   15. Ans.(A) S, (B) R, (C) Q, (D) P

16	Ans.(A)	17.	Ans.(C)	18.	Ans.(A)	19.	Ans.(A)
20.	Ans.(C)	21.	Ans.(B)	22.	Ans.(C)	23.	Ans.(C)
24.	Ans.(D)	25.	Ans.(D)				

EXERCISE # J-MAINS

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

EXERCISE # J-ADVANCED

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