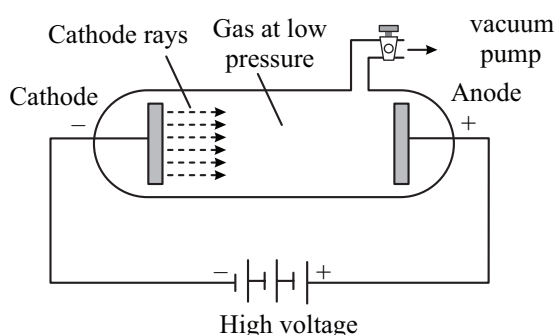


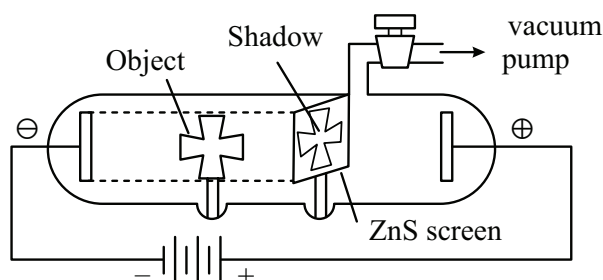
Atomic Structure

FUNDAMENTAL PARTICLES

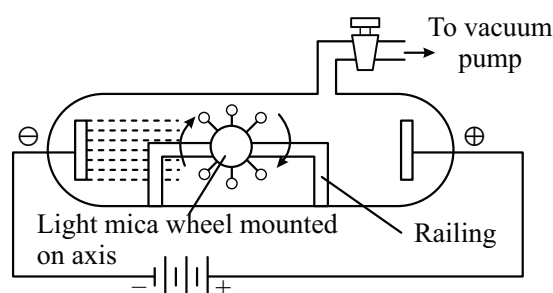
Cathode Rays - Discovery of Electron



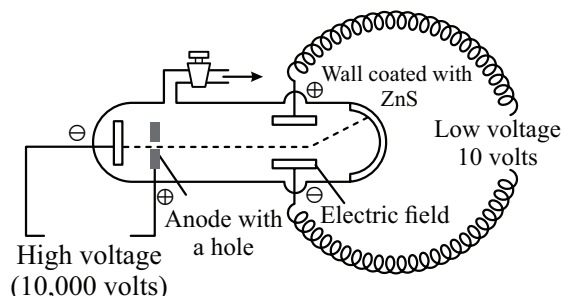
- (a) The electron was discovered as a result of the studies of the passage of electricity through gases at extremely low pressures known as Gas-discharge tube experiment.
- (b) When a high voltage of the order of 10,000 volts or more was applied across the electrodes, some sort of invisible rays moved from the negative electrode to the positive electrodes, these rays are called as cathode rays.
- (c) Cathode rays have the following properties.
 - (i) Path of travelling is straight from the cathode with a very high velocity, and it produces shadow of an object placed in its path.



- (ii) Cathode rays produce mechanical effects. If a small pedal wheel is placed between the electrodes, it rotates. This indicates that the cathode rays consist of matter.



- (iii) When electric and magnetic fields are applied to the cathode rays in the discharge tube, the rays are deflected thus establishing that they consist of charged particles.



- (iv) Cathode rays produce X-rays when they strike against hard metals like tungsten, copper etc.
- (v) When the cathode rays are allowed to strike on a thin metal foil, it gets heated up.
- (vi) They produce a green glow when strike the glass wall beyond the anode. Light is emitted when they strike the zinc sulphide screen.
- (vii) Cathode rays penetrate through thin sheets of aluminium and other metals.
- (viii) They affect the photographic plates.
- (ix) **The ratio of charge to mass i.e. charge/mass is same for all the cathode rays irrespective of the gas used in the tube.**

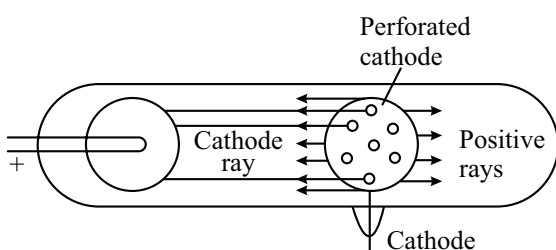
Properties of Electron:

- (a) The first precise measurement of the charge on an electron was made by Robert A. Millikan in 1909 by oil drop experiment. Its value was found to be -1.6022×10^{-19} coulomb.

- (b) The value of e/m has been found to be -1.7588×10^{11} C/kg.
- (c) The mass of electron (9.1096×10^{-31} Kg) can be calculated from the value of e/m and the value of charge of electron.
- (d) The molar mass of electron is 5.48×10^{-4} g/mole.

Positive Rays-Discovery of Proton

- (a) The existence of positively charged particles in an atom was shown by E. Goldstein in 1886.
- (b) He repeated the Gas discharge tube experiments by using a perforated cathode.
- (c) It was observed that when a high potential difference was applied between the electrodes, not only cathode rays were produced but also a new type of rays were produced simultaneously from anode moving towards cathode and passed through the holes or canal of the cathode. These rays are termed as canal rays or cathode rays.



- (d) Characteristics of Anode Rays are as follows.
 - (i) These rays travel in straight lines and cast shadow of the object placed in their path.
 - (ii) The anode rays are deflected by the magnetic and electric fields like cathode rays but direction is opposite that mean these rays are positively charged.
 - (iii) These rays have kinetic energy and produces heating effect also.
 - (iv) The e/m ratio of these rays is smaller than that of electrons.
 - (v) **Unlike cathode rays, their e/m value is dependent upon the nature of the gas taken in the tube.**
 - (vi) These rays produce flashes of light on ZnS screen.
 - (vii) These rays can pass through thin metal foils.
 - (viii) They are capable to produce ionisation in gases.

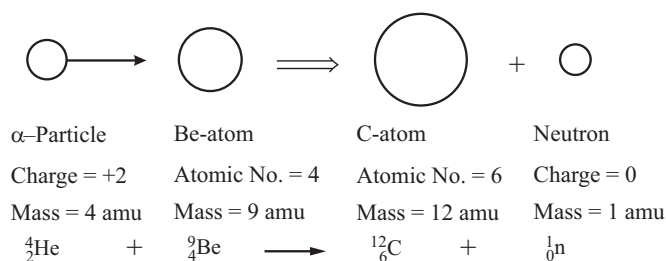
Properties of Proton

- (a) Proton carries a charge of $+1.602 \times 10^{-19}$ coulomb, i.e., one unit positive charge.
- (b) Mass of proton is 1.672×10^{-27} kg or 1.0072 amu.
- (c) A proton is defined as a sub-atomic particle which has a mass nearly 1 amu and a relative charge of +1 unit.

Discovery of Neutron

- (i) This was discovered 20 years after the structure of atom was elucidated by Rutherford.

- (ii) It has been found that for all atoms except hydrogen atomic mass is more than the atomic number. Thus Rutherford (1920) suggested that in an atom, there must be present at least a third type of fundamental particle.
- (iii) It should be electrically neutral and posses mass nearly equal to that of proton. He proposed its name as neutron.
- (iv) In 1932, **Chadwick** bombarded beryllium with a stream of α -particles. He observed that penetrating radiations were produced which were not affected by electric & magnetic fields. These radiations consists of neutral particles, which were called **neutrons**. The nuclear reaction can be shown as.



Properties of Neutron

- (a) A neutron is a sub atomic particle which has a mass 1.675×10^{-24} g approximately 1amu, or nearly equal to the mass of proton or hydrogen atom and carrying no electrical charge.
- (b) The specific charge (e/m value) of a **neutron** is zero.



Train Your Brain

Example 1: Which has highest e/m ratio?

- (a) He^{2+}
- (b) H^+
- (c) He^+
- (d) H

Sol. Mass of H^+ is minimum

Example 2: Arrange the following particles in increasing order of values of e/m ratio: Electron (e), proton (p), neutron (n) and α -particle (α):

- (a) n, p, e, α
- (b) n, α , p, e
- (c) n, p, α , e
- (d) e, p, n, α

Sol.

	Electron	Proton	Neutron	α -particle
e	1 unit	1 unit	zero	2 units
m	1/1837 unit	1 unit	1 unit	4-units
e/m	1837	1	zero	1/2

Example 3: Mass of neutron is times the mass of electron:

- (a) 1840
- (b) 1480
- (c) 2000
- (d) None of these

Sol. Mass of neutron = 1.675×10^{-27} kg, mass of electron = 9.108×10^{-31} kg.



Concept Application

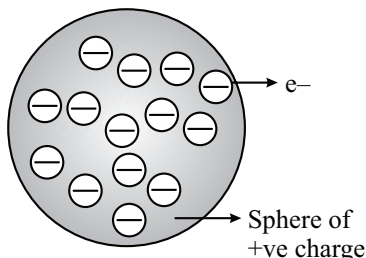
1. The mass of cathode ray particle is:

- Same for different gases
- Different for different gases
- Minimum for H_2 gas
- Different for same gases

THOMSON'S MODEL OF ATOM

Thomson was the first to propose a detailed model of the atom.

Thomson proposed that an atom consists of a uniform sphere of positive charge in which the electrons are distributed more or less uniformly.



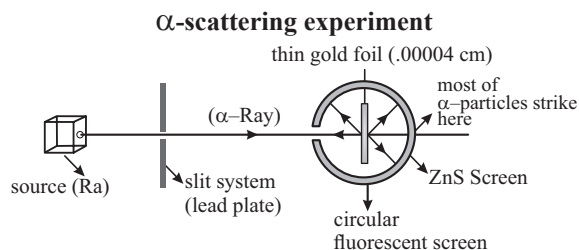
This model of atom is known as “Plum-Pudding model” or “Raisin Pudding Model” or “Water Melon Model”.

Drawbacks: An important drawback of this model is that the mass of the atoms is considered to be evenly spread over that atom.

It is a static model. It does not reflect the movement of electron.

It couldn't explain the stability of an atom.

RUTHERFORD'S SCATTERING EXPERIMENT

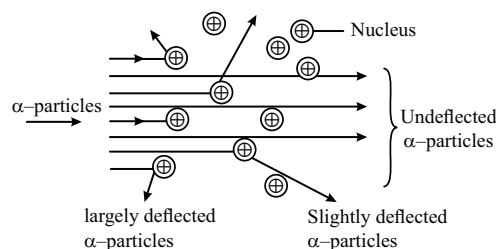


Rutherford Observed that

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

Following conclusions were drawn from the above observations:

- Since most of the α -particle went straight through the metal foil undeflected, it means that there must be very large empty space within the atom.



- Since few of the α -particles were deflected from their original paths through moderate angles; it was concluded that whole of the +ve charge is concentrated and the space occupied by this positive charge is very small in the atom.

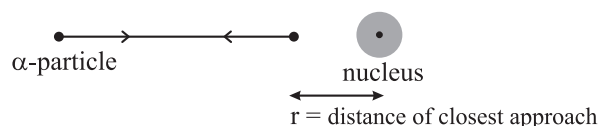
When α -particles come closer to this point, they suffer a force of repulsion and deviate from their paths.

The positively charged heavy mass which occupies only a small volume in an atom is called **nucleus**. It is supposed to be present at the centre of the atom.

- A very few of the α -particles suffered strong deflections or even returned on their path indicating that the nucleus is rigid and α -particles recoil due to direct collision with the heavy positively charged mass.
- Almost all mass of the atom is densely concentrated in extremely small region (nucleus).
- 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.

DISTANCE OF CLOSEST APPROACH

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



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

$$\text{K.E.} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 \cdot q_2}{r} = \frac{1}{4\pi\epsilon_0} \cdot \frac{(2e) \cdot (Ze)}{r}$$

$$r = \frac{2Ze^2}{(4\pi\epsilon_0)(\text{K.E.})}$$

where Z = atomic number of element used in foil.

APPLICATIONS OF RUTHERFORD MODEL

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

$$\frac{R_A}{R_N} = \frac{\text{Radius of the atom}}{\text{Radius of the nucleus}} = \frac{10^{-8} \text{ cm}}{10^{-13} \text{ cm}} = 10^5,$$

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

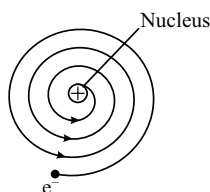
Where $R_0 = 1.33 \times 10^{-13}$ (a constant) and $A = \text{mass number}$ ($p + n$) and $R = \text{radius of the nucleus}$.

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

$$\frac{\text{volume of the atom}}{\text{volume of the nucleus}} = \frac{(10^{-8})^3}{(10^{-13})^3} = 10^{15}$$

Drawbacks of Rutherford Model

This theory could **not** explain stability of atom. According to Maxwell, electron loses its energy continuously in the form of electromagnetic radiations. As a result of this, the e^- should lose energy at every turn and move closer and closer to the nucleus following a spiral path. The ultimate result will be that it will fall into the nucleus, thereby making the atom unstable.



Train Your Brain

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

$$\text{Sol. K.E.} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r}$$

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

$$\Rightarrow r = \frac{9 \times 10^9 \times 2 \times 1.6 \times 10^{-19} \times 79}{10 \times 10^6} = 2.275 \times 10^{-14} \text{ m}$$

(From the above example it is clear that nuclear dimension cannot be greater than $3 \times 10^{-14} \text{ m}$.)

Example 5: An α -particles is projected towards the following nucleus with same kinetic energy in different experiment the distance of closest approach is maximum for

- (a) Na ($Z = 11$) (b) Ca ($Z = 20$)
(c) Ag ($Z = 47$) (d) Au ($Z = 79$)

$$\text{Sol. K.E.} = \frac{k q_1 q_2}{r}$$

$q_1 = \text{charge of } \alpha\text{-particle}$

$q_1 = \text{charge on nucleus of given element}$

$$\text{therefore, } r = \frac{k q_1 q_2}{\text{K.E.}}$$

if K.E. = constant & $q_1 = 2e^-$

then $r \propto q_2$ i.e., atomic number of other element.

Concept Application

2. Rutherford's alpha particle scattering experiment eventually led to the conclusion that
 - (a) Mass and energy are related
 - (b) Electrons occupy space around the nucleus
 - (c) Neutrons are buried deep in the nucleus
 - (d) The point of impact with matter can be precisely determined

ATOMIC NUMBER (Z) AND MASS NUMBER (A)

Atomic number (Z) of an element

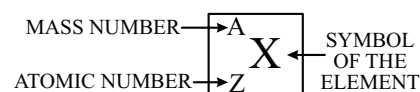
= Total number of protons present in the nucleus.

= Total number of electrons present in the neutral atom.

- ❖ Since the electrons have negligible mass, the entire mass of the atom is mainly due to protons and neutrons only. Since these particles are present in the nucleus, therefore they are collectively called **nucleons**.
- ❖ As each of these particles has one unit mass on the atomic mass scale, therefore the sum of the number of protons and neutrons will be nearly equal to the mass of the atom (in amu).

Mass number of an element = No. of protons (Z) + No. of neutrons (n).

- ❖ The mass number of an element is nearly equal to the atomic mass of that element.
- ❖ The atomic number (Z) and mass number (A) of an element 'X' are usually represented along with the symbol of the element as



- (i) **Isotopes:** Such atoms of the same element having same atomic number but different mass numbers are called isotopes.
e.g. ${}^1_1\text{H}$, ${}^2_1\text{D}$ and ${}^3_1\text{T}$ and isotopes of hydrogen.
- (ii) **Isobars:** Such atoms of different elements which have same mass numbers (and of course different atomic numbers) are called isobars.
e.g. ${}^{40}_{18}\text{Ar}$, ${}^{40}_{19}\text{K}$, ${}^{40}_{20}\text{Ca}$.
- (iii) **Isotones:** Such atoms of different elements which contain the same number of neutrons are called isotones.
e.g. ${}^{14}_6\text{C}$, ${}^{15}_7\text{N}$, ${}^{16}_8\text{O}$.
- (iv) **Isoelectronic species:** The species (atoms or ions) containing the same number of electrons are called isoelectronic species.

For example: O^{2-} , F^- , Na^+ , Mg^{2+} , Al^{3+} , Ne all contain 10 electrons each and hence they are isoelectronic.

- (v) **Isodiaphers:** Such atoms having same difference in the number of protons and neutrons in their nucleus i.e., same value of $(n-p)$.

e.g. U_{92}^{238} and Th_{90}^{234}

NATURE OF LIGHT AND NATURE OF ELECTROMAGNETIC RADIATION

Nature of Light

- ❖ **Maxwell electromagnetic wave theory (wave nature of light):** An accelerated electrically charged particle produces and transmits electrical and magnetic field. These are transmitted in the form of waves known as electromagnetic waves or electromagnetic radiations.

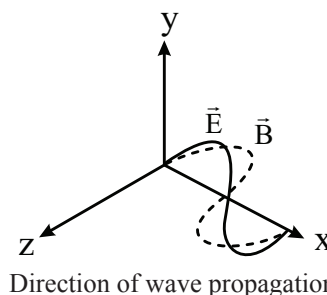
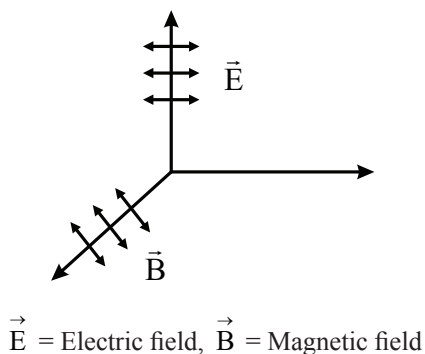
He stated that light also possess electrical and magnetic field and it is also known as electromagnetic radiations.

- ❖ **Characteristics of Electromagnetic Radiations:**

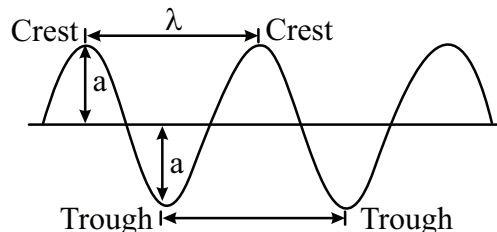
- In these electromagnetic radiation electrical and magnetic field oscillates perpendicular to each other and it also propagates perpendicular to both field.
- All these electromagnetic radiation do not require any medium and can travel in vacuum.
- Velocity of all electromagnetic radiations is 3×10^8 m/s in vacuum.
- Energy of an electromagnetic wave is directly proportional to intensity and it is independent of frequency.
- They also show diffraction and interference and therefore, Maxwell concluded light to be wave nature.

Electromagnetic Wave Radiation

The form of energy which propagates in form of the oscillating electrical/magnetic field are called electromagnetic radiations.



Some important characteristics of a wave:



- Wavelength** of a wave is defined as the distance between any two consecutive crests or troughs. It is represented by λ (Lambda) and is expressed in \AA or m or cm or nm (nanometer) or pm (picometer).
 $1 \text{ \AA} = 10^{-8} \text{ cm} = 10^{-10} \text{ m}$
 $1 \text{ nm} = 10^{-9} \text{ m}$, $1 \text{ pm} = 10^{-12} \text{ m}$
- Frequency** of a wave is defined as the number of waves passing through a point in one second. It is represented by ν (nu) and is expressed in Hertz (Hz) or cycles/sec or simply sec^{-1} or s^{-1} .
 $1 \text{ Hz} = 1 \text{ cycle/sec}$
- Velocity** of a wave is defined as the linear distance travelled by the wave in one second. It is represented by v and is expressed in cm/sec or m/sec (ms^{-1}).
- Amplitude** of a wave is the height of the crest or the depth of the trough. It is represented by 'A' and is expressed in the units of length.
- Wave number** is defined as the number of waves present in 1 cm length. Evidently, it will be equal to the reciprocal of the wavelength. It is represented by $\bar{\nu}$ (read as nu bar).

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

If λ (Lambda) is expressed in cm, $\bar{\nu}$ will have the units cm^{-1} .

Relationship between velocity, wavelength and frequency of a wave: As frequency is the number of waves passing through a point per second and λ is the length of each wave, hence their product will give the velocity of the wave.

$$\text{Wave speed} = \text{Frequency} \times \text{Wavelength}$$

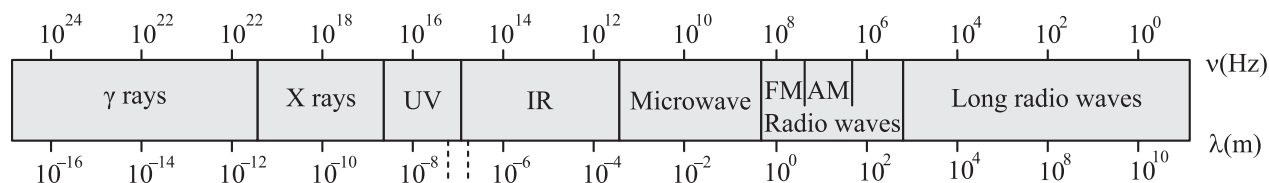
ELECTRO MAGNETIC SPECTRUM

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

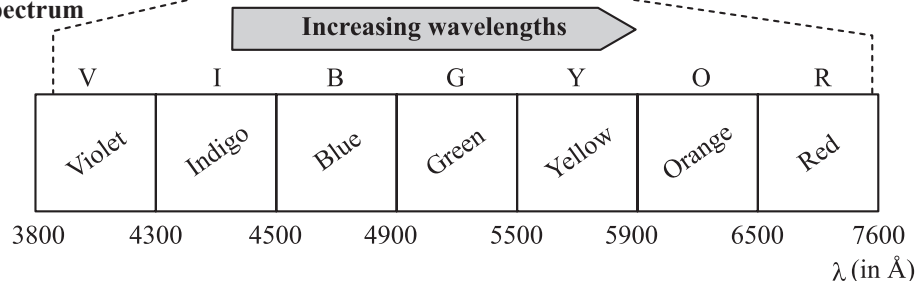
Order of wavelength in Electromagnetic spectrum:

Cosmic rays < γ -rays < X-rays < Ultraviolet rays < Visible < Infrared < Micro waves < Radio waves.

(a) The spectrum of electromagnetic radiation.



(b) Visible spectrum



Note: The visible region is only a small part of the entire spectrum.

PLANCK'S QUANTUM THEORY

Particle nature of light: He stated that a body radiates energy in the form of discontinuous energy packets or bundles. Each bundle of energy is known as quantum and quantum of light is known as photons.

Energy of each quantum is directly proportional to frequency of radiation.

$$E \propto \nu$$

$$E = h\nu \quad h = 6.62 \times 10^{-34} \text{ J-s}$$

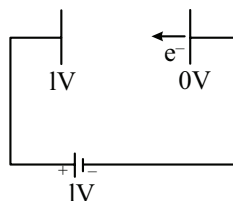
↓
Planck's constant

Total energy absorbed or emitted by a body will be whole no. integral multiple of energy of quantum.

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

Key Note

- One electron volt (e.v.):** Energy gained by an electron when it is accelerated from rest through a potential difference of 1 volt.
- Positive charge always moves from high potential to low potential and -ve charge always moves from low potential to high potential if set free.
- If a charge 'q' is accelerated through a potential difference of 'V' volt then its kinetic energy will be increased by $q \times V$.
 $1\text{eV} = 1.6 \times 10^{-19} \text{ C} \times 1 \text{ volt}$
 $\therefore 1\text{eV} = 1.6 \times 10^{-19} \text{ J}$



Train Your Brain

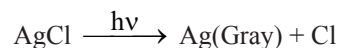
Example 6: Calculate the no. of photons emitted by 60 watt bulb in 10 hrs, when light of wavelength 6000 Å is emitted by it.

$$\text{Sol. } P = \frac{E}{t} = \frac{nh\nu}{t} \quad \text{or } P = \frac{nhc}{\lambda t} \quad \text{or } n = \frac{P \times \lambda \times t}{h \times c}$$

$$\text{or } n = \frac{60 \times 6000 \times 10^{-10} \times 10 \times 60 \times 60}{6.626 \times 10^{-34} \times 3 \times 10^8}$$

$$\text{or } n = 6.52 \times 10^{24}$$

Example 7: Certain sun glasses have small amount of AgCl incorporated in the lenses which on exposure to light of appropriate wavelength turns to gray colour to reduce the glare following the reactions:



If the heat of reaction for the decomposition of AgCl is 248 kJ mol^{-1} , what maximum wavelength is needed to induce the desired process?

Sol. Energy needed to change = $248 \times 10^3 \text{ J/mol}$

If photon is used for this purpose, then according to Einstein law one molecule absorbs one photon.
Therefore,

$$\therefore N_A \cdot \frac{hc}{\lambda} = 248 \times 10^3$$

$$\lambda = \frac{6.626 \times 10^{-34} \times 3.0 \times 10^8 \times 6.022 \times 10^{23}}{248 \times 10^3}$$

$$= 4.83 \times 10^{-7} \text{ m}$$

Example 8: A bulb is rated as 110 watt. If it emits 25% of absorbed energy as red light ($\lambda = 6626\text{\AA}$), how many photons are emitted out by the bulb per second?

Sol. $P \times \eta = \frac{n \times h \times c}{\lambda \times t}$
 or $110 \times \frac{25}{100} = n \times \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{6626 \times 10^{-10}}$
 or $n = 9.2 \times 10^{19}$

Example 9: Wavelength of micro wave 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. $\left(\frac{nhc}{\lambda}\right) \times \frac{25}{100} = ms\Delta t$
 $n \times \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{0.08} \times \frac{25}{100} = 400 \times 4.2 \times 20$
 \therefore Number of moles of photon = $\frac{n}{N_A}$
 or Number of moles of photon = $\frac{540.89 \times 10^{26}}{6.022 \times 10^{23}}$
 $= 9.0 \times 10^4 \text{ mol.}$

Example 10: 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. $E_a \times \frac{40}{100} = E_e$
 $n_a \times \frac{hc}{4000\text{\AA}} \times \frac{40}{100} = n_e \times \frac{hc}{5000\text{\AA}}$
 $\frac{n_e}{n_a} = \frac{40}{100} \times \frac{5000}{4000} = \frac{1}{2} \Rightarrow \frac{n_e}{n_a} = \frac{1}{2}$

Concept Application

- Photon of which light has maximum energy:
 (a) Red (b) Blue
 (c) Violet (d) Green
- Two bulbs 'A' and 'B' emit red light and yellow light at 8000 Å and 4000Å respectively. The number of photons emitted by both the bulbs per second is the same. If the red bulb is labelled as 100 watts, find the wattage of the yellow bulb.
 (a) 100 watt (b) 200 watt
 (c) 300 watt (d) 400 watt

5. The Vividh Bharati Station of All India Radio, Delhi broadcasts on a frequency of 1368 kHz (kilo hertz). Calculate the wavelength and wave number of the electromagnetic radiation emitted by the transmitter.

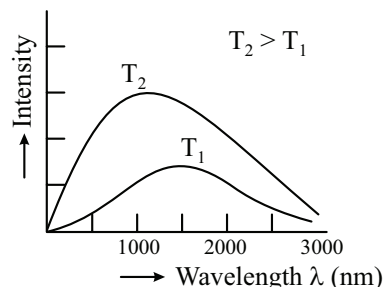
- (a) (219.3 m, $4.56 \times 10^{-3} \text{ m}^{-1}$)
 (b) (219.2 m, $4.46 \times 10^{-3} \text{ m}^{-1}$)
 (c) (218.3 m, $4.56 \times 10^{-3} \text{ m}^{-1}$)
 (d) (219.5 m, $4.58 \times 10^{-3} \text{ m}^{-1}$)

APPLICATION OF PLANCK'S QUANTUM THEORY

Black Body Radiation:

When solids are heated they emit radiation over a wide range of wavelengths.

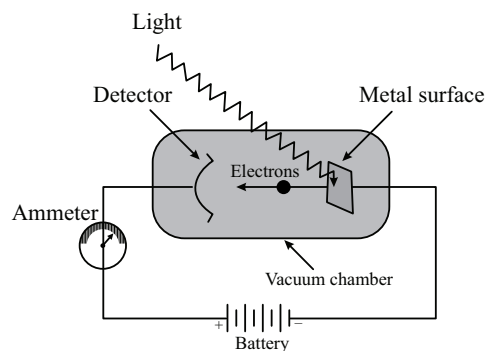
The ideal body, which emits and absorbs all frequencies, is called a black body and the radiation emitted by such a body is called black body radiation. The exact frequency distribution of the emitted radiation (i.e., intensity versus frequency curve of the radiation) from a black body depends only on its temperature.



The above experimental results cannot be explained satisfactorily on the basis of the wave theory of light. Planck suggested that atoms and molecules could emit (or absorb) energy only in discrete quantities.

Photoelectric Effect:

When certain metals (for example: Potassium, Rubidium, Caesium etc.) were exposed to a beam of light electrons were ejected as shown in Fig.



The phenomenon is called **Photoelectric effect**. The results observed in this experiment were:

- ❖ The electrons are ejected from the metal surface as soon as the beam of light strikes the surface, i.e., there is no time lag between the striking of light beam and the ejection of electrons from the metal surface.
- ❖ The number of electrons ejected is proportional to the intensity or brightness of light.

TERMS USED IN PHOTO ELECTRIC EFFECT

- 1. Work function (w):** It is the minimum amount of energy required to cause a photo emission from the metal surface. It is also known as threshold energy or Binding energy. Work function depends upon ionisation energy and therefore w is minimum for alkali metals.
- 2. Threshold frequency (ν_0):** The minimum value of frequency that can cause photo emissions. If $\nu < \nu_0$, then there is no photo emission.

$$w = h\nu_0 \Rightarrow w = \frac{hc}{\lambda_0}$$

- 3. Threshold wavelength (λ_0):** The maximum value of wavelength that can cause photo emission.
If $\lambda > \lambda_0$, then photo emission is not possible.
- 4. Intensity (I):** Energy falling on metal surface of unit area per unit time.

$$I = \frac{E}{At} = \frac{nh\nu}{At}$$

- 5. Photo intensity (I_p):** It is number of photons falling per unit area per unit time.

$$I_p = \frac{n}{At}$$

Relation between I and I_p :

$$I = I_p h\nu$$

Photo intensity is independent of frequency while intensity depends on frequency.

Power: Total energy radiated per unit time.

$$P = \frac{E}{t} = \frac{nh\nu}{t}$$

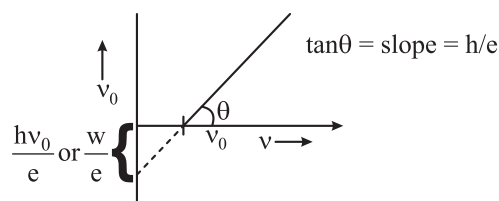
SATURATION CURRENT & STOPPING POTENTIAL

It is the minimum potential required to stop the fastest moving electrons completely or it is the minimum potential at which photo current becomes zero.

$$eV_0 = h\nu - w$$

$$eV_0 = h\nu - h\nu_0$$

$$\Rightarrow V_0 = \frac{h\nu}{e} - \frac{h\nu_0}{e}$$



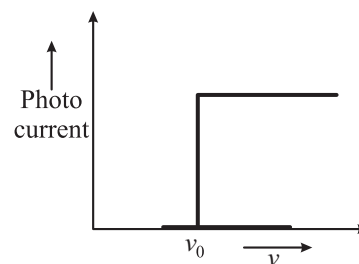
It can be commented that stopping potential increase with increase in frequency. However, if photo intensity is changed there is no effect on stopping potential.

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 increases.

EFFECT OF VARIATION OF FREQUENCY

- (a) **Effect on Photo Emission:** $I = I_p h\nu$

If frequency of subjected photon increases (intensity increases keeping photo intensity constant) then there is no change in no. of ejected photo electrons as well as no change in photo current.



- (b) **Effect on kinetic Energy:** Average K. E. as well as K. E_{\max} increases with increases in frequency.

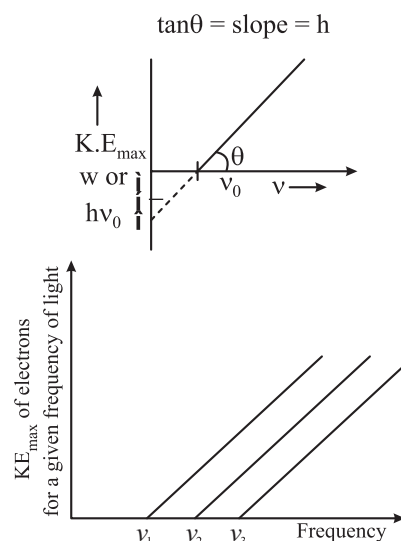
$$h\nu - W = KE_{\max}$$

$$KE_{\max} = h\nu - h\nu_0$$

$$y = mx + c$$

$$KE_{\max} = h\nu - \frac{hc}{\lambda_0}$$

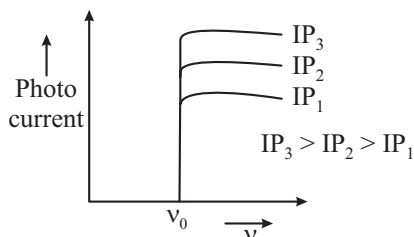
$$KE_{\max} = h\nu - w$$



The diagram shows the interdependence between light frequency and the $K.E._{max}$ of electrons emitted from metal. It shows the interdependence for three different metals. See that it clearly shows the limiting frequencies are different for different metals.

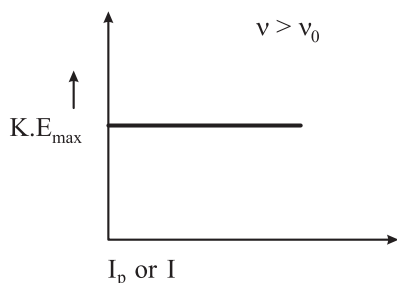
Effect of Variation of Photo Intensity

On increasing intensity, keeping frequency constant (i.e. increasing photo intensity) no. of ejected photo electrons increases as well as photo current increases.



Effect on Kinetic Energy

Average $K.E.$ and $K.E._{max}$ remains constant with change in photo intensity



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

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

$$\text{Therefore } E = \frac{6.6 \times 10^{-19} \text{ J}}{1.6 \times 10^{-19} \text{ J/eV}} = 4.125 \text{ eV}$$

(ii) Kinetic energy of the emitted photo electron

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

$$\text{Therefore, K.E.} = 4.125 - 2.20$$

$$= 1.925 \text{ eV} = 3.08 \times 10^{-19} \text{ J}$$

(iii) Velocity of the photo electron

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

Therefore,

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

Example 13: The threshold frequency ν_0 for a metal is $6 \times 10^{14} \text{ s}^{-1}$. Calculate the kinetic energy of an electron emitted when radiation of frequency $\nu = 1.1 \times 10^{15} \text{ s}^{-1}$ hits the metal.

$$\text{Sol. K.E.} = \frac{1}{2}m_e v^2 = h(\nu - \nu_0)$$

$$\therefore K.E. = (6.626 \times 10^{-34})(1.1 \times 10^{15} - 6 \times 10^{14})$$

$$= 3.3 \times 10^{-19} \text{ J}$$



Train Your Brain

Example 11: Ultraviolet light of wavelength 200 nm is used in an experiment of photoelectric effect with lithium cathode ($w = 2.5 \text{ eV}$). Then calculate

(i) $K.E._{max}$

(ii) Stopping potential

$$\text{Sol. } K.E._{max} = \frac{hc}{\lambda} - w$$

$$K.E._{max} = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{200 \times 10^{-9} \times 1.6 \times 10^{-19}} - 2.5 \text{ eV}$$

$$= 6.2 - 2.5 = 3.7 \text{ eV}$$

$$\text{Stopping Potential} = 3.7 \text{ V}$$

Example 12: 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



Concept Application

- A photon of energy $h\nu$ is absorbed by a free electron of a metal having work function $w < h\nu$. Then :
 - The electron is sure to come out
 - The electron is sure to come out with a kinetic energy $(h\nu - w)$
 - Either the electron does not come out or it comes with a kinetic energy $(h\nu - w)$
 - It may come out with a kinetic energy less than $(h\nu - w)$
- A beam of white light is dispersed into its wavelength components by a Quartz prism and falls on a thin sheet of potassium metal. What is the correct decreasing order of kinetic energy of the electron emitted by the different light component?
 - blue > green > orange > yellow
 - violet > blue > orange > red
 - yellow > green > blue > violet
 - orange > yellow > blue > violet

8. A laser producing monochromatic lights of different wavelength is used to eject electron from the sheet of gold having threshold frequency $6.15 \times 10^{14} \text{ s}^{-1}$. Which of the following incident radiation will be suitable for the ejection of electrons?

- 1.5 moles of photons having frequency $3.05 \times 10^{14} \text{ s}^{-1}$
- 0.5 moles of photon of frequency $12.3 \times 10^{12} \text{ s}^{-1}$
- One photon with frequency $5.16 \times 10^{15} \text{ s}^{-1}$
- All of the above

9. The number of photoelectrons emitted depends upon:

- The intensity of the incident radiation
- The frequency of the incident radiation
- The product of intensity and frequency of incident radiation
- None of these

BOHR'S MODEL

It was the first model based on Planck's quantum theory and the model explained stability of atom and line spectrum of hydrogen.

Postulates of Bohr's Model

- An atom consist of centrally located small, dense, positively charged nucleus and electrons are revolving around the nucleus in circular paths known as circular orbits and coulombic force of attraction between nucleus and electron is balanced by centrifugal force of the revolving electron.
- Out of the infinite circular orbits only those circular orbits are possible in which angular momentum of electron is integral multiple of $h/2\pi$ i.e. angular momentum of an electron can have fixed values like $\frac{h}{2\pi}, \frac{2h}{2\pi}, \frac{3h}{2\pi}$ etc. i.e., angular momentum of electron is quantised.

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

m and v are mass and velocities of electron respectively. r is radius of orbit and n is integer which is later related with orbit number or shell number and h is Planck's constant.

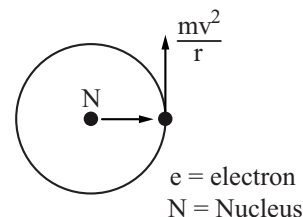
- The energy of these circular orbits have fixed values and hence electron in an atom can have only certain values of energy. It is characteristic of an orbit and it cannot have any orbit value of its own. And therefore energy of an electron is also quantised.
- As long as electrons remains in these fixed orbits, it doesn't loose energy i.e., energy of an electron is stationary (not changing with time) and therefore these orbits are known as allowed energy levels or stationary states and this explains the stability of atom.
- The energy levels are designated as K, L, M, N and numbered as 1, 2, 3, 4 etc from nucleus outwards and as the distance of the shells or energy level from the nucleus increases the energy of the energy level also increases i.e., $E_N > E_M > E_L > E_K$

- The emission or absorption of energy in the form of radiations can only occur when an electron jump from one stationary orbit to other.

$$\Delta E = E_{\text{higher}} - E_{\text{lower}}$$

$\Delta E = h\nu$, where $h\nu$ is the energy of absorbed photon or emitted photon which corresponds to the difference in energy levels. Energy is absorbed when electron jumps from lower energy level (normal state) to higher energy level (excited state) and energy is emitted when electrons jumps from higher energy level to lower energy level.

❖ Bohr's model is applicable for one electron species only, like H, He^+ , Li^{2+} , Be^{3+} etc.



$$mvr = \frac{nh}{2\pi} \quad \dots(i)$$

$$q_1 = e, q_2 = Ze$$

$$\frac{mv^2}{r} = \frac{kq_1q_2}{r^2} = \frac{kZe^2}{r^2} \quad \dots(ii)$$

Derivation of Radius of Shell

$$\Rightarrow \frac{mn^2h^2}{4\pi^2m^2r^2 \cdot r} = \frac{kZe^2}{r^2}$$

$$\Rightarrow r = \frac{mn^2h^2}{4\pi^2m^2kZe^2} \Rightarrow \boxed{r = \frac{n^2h^2}{4\pi^2mkZe^2}}$$

$$r = 0.529 \times \frac{n^2}{Z} \text{ \AA} \Rightarrow r \propto \frac{n^2}{Z}$$

For a particular atom $r \propto n^2$

Radius of 1st orbit of H atom

$$r = 0.529 \text{ \AA}$$

Derivation of Velocity of Electron in Bohr's Orbit

$$v = \frac{nh}{2\pi mr}, \text{ putting value of } r.$$

$$v = \frac{nh \times 4\pi^2mkZe^2}{2\pi mn^2h^2}$$

$$v = \frac{2\pi kZe^2}{h.n.} = \frac{2\pi ke^2}{h} \times \frac{Z}{n}$$

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

$$v \propto \frac{Z}{n}$$

Derivation of Total Energy of Electron/System

T.E. of system = K.E. of e^- + P.E. of system (nucleus and e^-)

$$\text{Kinetic energy of electron} = \frac{1}{2}mv^2 = \frac{1}{2} \frac{kZe^2}{r}$$

$$\text{P.E.} = -\frac{kZe^2}{r}$$

$$\text{T.E.} = \frac{-kZe^2}{2r} \quad \left[r = \frac{n^2 h^2}{4\pi^2 m^2 kZe^2} \right]$$

$$\text{T.E.} = -13.6 \times \frac{Z^2}{n^2} \text{ eV/atom} \quad \dots(i)$$

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

As shell no. or distance increases, the value of T.E. and P.E. increases (however magnitude decreases) and becomes maximum at infinity i.e., zero.

$$\text{K.E.} = -\frac{\text{P.E.}}{2}$$

$$\text{T.E.} = \frac{\text{P.E.}}{2}$$

$$\text{T.E.} = -\text{K.E.}$$

Calculation of Energy of Energy Levels in H atom

(i) When $n = 1$ (ground level)

$$\text{K.E.} = 13.6 \text{ eV (atom)}$$

$$\text{P.E.} = -27.2 \text{ eV / atom}$$

$$\text{T.E.} = -13.6 \text{ eV/atom}$$

(ii) When $n = 2$ / 2nd energy level / 1st excited state

$$\text{K.E.} = \frac{13.6}{4} \text{ eV/atom} = 3.4 \text{ eV / atom}$$

$$\text{P.E.} = -6.8 \text{ eV/atom}$$

$$\text{T.E.} = -3.4 \text{ eV/atom}$$

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

(iii) When $n = 3$ / 3rd energy level / 2nd excited state.

$$\text{K.E.} = \frac{13.6}{9} \text{ eV/atom} = 1.51 \text{ eV/atom}$$

$$\text{P.E.} = -3.02 \text{ eV/atom}$$

$$\text{T.E.} = -1.51 \text{ eV/atom}$$

$$E_3 - E_2 = -1.51 \text{ eV/atom} + 3.4 \text{ eV/atom} = 1.89 \text{ eV atom.}$$

(iv) When $n = 4$ / 4th excited state

$$\text{K.E.} = \frac{13.6}{4^2} \Rightarrow \frac{13.6}{16} = 0.85 \text{ eV/atom}$$

$$\text{P.E.} = -1.70 \text{ eV/atom}$$

$$\text{T.E.} = -0.85 \text{ eV/atom}$$

$$E_4 - E_3 = 0.66$$

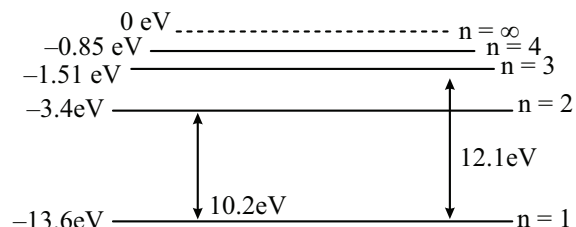
As distance increases (n increases) energy of the energy level increases but energy difference between consecutive energy level keeps on decreasing i.e., maximum energy difference is between 2 to 1 (among consecutive orbits).

Conclusion from Equation of Energy

- The negative sign of energy indicates that there is attraction between the negatively charged electron and positively charged nucleus.
- All the quantities on R.H.S. in the energy equation are constant for an element having atomic number Z except ' n ' which is an integer such as 1,2,3, etc. i.e. the energy of an electron is constant as long as the value of ' n ' is kept constant.
- The energy of an electron is inversely proportional to the square of ' n ' with negative sign.

Energy Level Diagram

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



Definitions Valid for Single Electron System

(i) **Ground state:** Lowest energy state of any atom or ion is called ground state of the atom, it is $n = 1$.

Ground state energy of H-atom = -13.6 eV

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

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

$n = 2$ First excited state

$n = 3$ Second excited state

$n = 4$ Third excited state

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

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

Ionisation energy of H-atom = 13.6 eV

Ionisation energy of He^+ ion = 54.4 eV

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

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

I.P. of H atom = 13.6 eV , I.P. of He^+ ion = 54.4 eV

(v) **Excitation Energy:** Energy required to move an electron from ground state of the atom to any other state of the atom is called excitation energy of that state.

Excitation energy of 2nd state = Excitation energy of 1st excited state = 1st excitation energy = 10.2 eV.

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

e.g. in H-atom excitation potential of third state = excitation potential of second excited state = second excitation potential = 12.1 eV.

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

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

Failures/Limitations of Bohr's theory

- He could not explain the line spectra of atoms containing more than one electron.
- He also could not explain the presence of multiple spectral lines.
- He was unable to explain the splitting of spectral lines in magnetic field (Zeeman effect) and in electric field (Stark effect).
- No conclusion was given for the principle of quantisation of angular momentum.
- He was unable to explain the de-Broglie's concept of dual nature of matter.
- He could not explain Heisenberg's uncertainty principle.



Train Your Brain

Example 14: A single electron system has ionization energy 11180 kJ mol⁻¹. Find the number of protons in the nucleus of the system.

Sol. I.E. = $\frac{Z^2}{n^2} \times 21.8 \times 10^{-19}$ J/atom

$$\frac{11180 \times 10^3}{6.022 \times 10^{23}} = \frac{Z^2}{1^2} \times 21.8 \times 10^{-19}$$

or $Z = 3$

Example 15: What are the frequency and wavelength of a photon emitted during a transition from $n = 5$ state to the $n = 2$ state in the hydrogen atom?

Sol. Since $n_i = 5$ and $n_f = 2$, this transition gives rise to a spectral line in the visible region of the Balmer series.

$$\Delta E = 2.18 \times 10^{-18} \text{ J} \left[\frac{1}{5^2} - \frac{1}{2^2} \right] = -4.58 \times 10^{-19} \text{ J}$$

It is an emission energy

The frequency of the photon (taking energy in terms of magnitude) is given by

$$\nu = \frac{\Delta E}{h} = \frac{4.58 \times 10^{-19} \text{ J}}{6.626 \times 10^{-34} \text{ Js}} = 6.91 \times 10^{14} \text{ Hz and}$$

$$c = \nu \lambda \text{ or } \lambda = \frac{3 \times 10^8}{6.91 \times 10^{14}} \text{ or } \lambda = 434 \text{ nm}$$

Example 16: The ionization energy of He⁺ is 19.6×10^{-18} J atom⁻¹. The energy of the first stationary state of Li²⁺ will be

- 21.2×10^{-18} J/atom
- 44.10×10^{-18} J/atom
- 63.2×10^{-18} J/atom
- 84.2×10^{-18} J/atom

Sol. E_1 for Li²⁺ = E_1 for H $\times Z^2_{\text{Li}} = E_1$ for H $\times 9$

E_1 for He⁺ = E_1 for H $\times Z^2_{\text{He}} = E_1$ for H $\times 4$

$$\begin{aligned} \text{or } E_1 \text{ for Li}^{2+} &= \frac{9}{4} E_1 \text{ for He}^+ \\ &= 19.6 \times 10^{-18} \times \frac{9}{4} \\ &= 44.10 \times 10^{-18} \text{ J/atom} \end{aligned}$$

Example 17: Calculate ratio of radius of 2nd orbit of H atom to 3rd orbit of Li²⁺ ion.

Sol. $\frac{\text{Radius of 2}^{\text{nd}} \text{ orbit of H atom}}{\text{Radius of 3}^{\text{rd}} \text{ orbit of Li}^{2+} \text{ atom}}$

$$= \frac{n^2}{z} \times \frac{z_1}{n_1^2} = \frac{4}{3}$$



Concept Application

10. Consider Bohr's theory for hydrogen atom. The magnitude of angular momentum, orbit radius and velocity of the electron in n^{th} energy state in a hydrogen atom are l , r & v respectively. Find out the value of 'x', if product of v , r and l (vrl) is directly proportional to n^x .

- ($x = 1$)
- ($x = 2$)
- ($x = 3$)
- ($x = 4$)

11. Correct order of radius of the 1st orbit of H, He⁺, Li²⁺, Be³⁺ is:

- H > He⁺ > Li²⁺ > Be³⁺
- Be³⁺ > Li²⁺ > He⁺ > H
- He⁺ > Be³⁺ > Li²⁺ > H
- He⁺ > H > Li²⁺ > Be³⁺

12. A single electron ion has nuclear charge $+Ze$ where Z is atomic number and e is electronic charge. It requires 16.52 eV to excite the electron from the second Bohr orbit to third Bohr orbit. Then atomic number and kinetic energy of electron in first Bohr orbit are respectively:

- (a) $Z = 3$, K.E. = 122.4 eV
 (b) $Z = 3$, K.E. = 122.2 eV
 (c) $Z = 2$, K.E. = 122.4 eV
 (d) $Z = 3$, K.E. = 121.4 eV

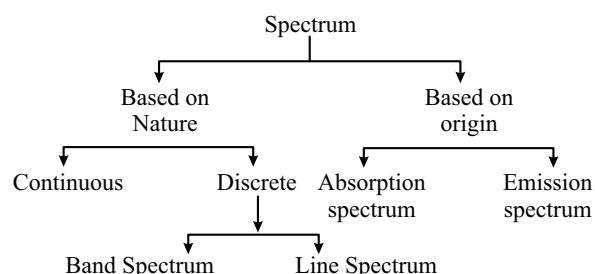
13. Match the following

A.	Energy of ground state of He^+	(i)	+ 6.04 eV
B.	Potential energy of I orbit of H-atom	(ii)	-27.2 eV
C.	Kinetic energy of II excited state of He^+	(iii)	54.4 V
D.	Ionisation potential of He^+	(iv)	- 54.4 eV

- (a) A – (i), B – (ii), C – (iii), D – (iv)
 (b) A – (iv), B – (iii), C – (ii), D – (i)
 (c) A – (iv), B – (ii), C – (i), D – (iii)
 (d) A – (ii), B – (iii), C – (i), D – (iv)

SPECTRUM

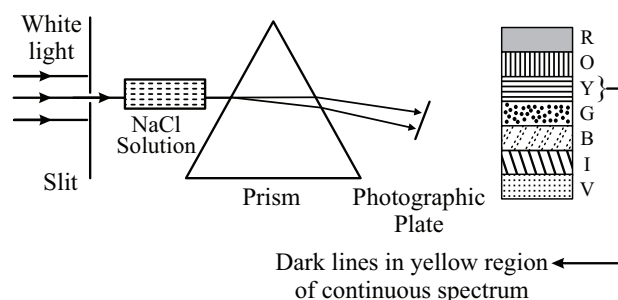
Study of Emission and Absorption Spectra: An instrument used to separate the radiation of different wavelengths (or frequencies) is called spectroscope or a spectrograph. Photograph (or the pattern) of the emergent radiation recorded on the film is called a spectrogram or simply a spectrum of the given radiation. The branch or science dealing with the study of spectra is called **spectroscopy**.



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

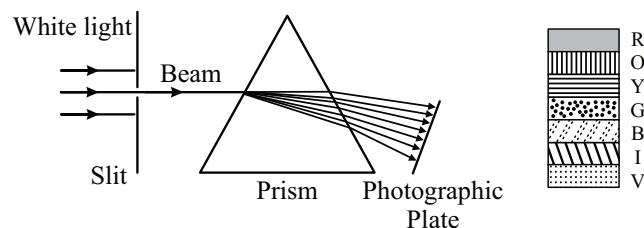
Absorption spectra: When white light from any source is first passed through the solution or vapours of a chemical substance and then analysed by the spectroscope, it is observed that some

dark lines are obtained in the continuous spectrum. These dark lines are supposed to result from the fact that when white light (containing radiations of many wavelengths) is passed through the chemical substance, radiations of certain wavelengths are absorbed, depending upon the nature of the element.



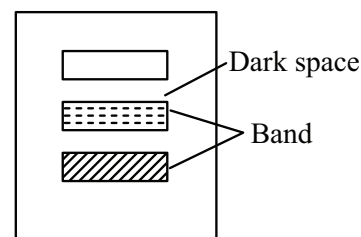
Depending upon the source of radiation, the emission spectra are mainly of two type:

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



Discontinuous Spectrum: It is of two type:

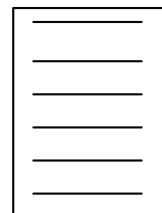
- (i) **Band spectrum**



Band spectrum contains colourful continuous bands separated by some dark space.

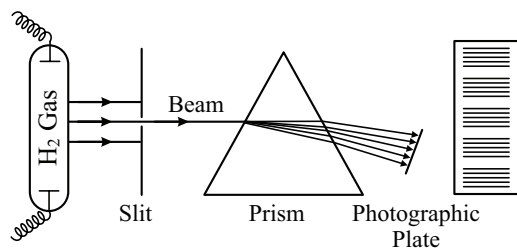
Generally molecular spectrum are band spectrum.

- (ii) **Line Spectrum:**



This is the ordered arrangement of lines of particular wavelength separated by dark space e.g. hydrogen spectrum. Line spectrum can be obtained from atoms.

Emission Spectrum of Hydrogen



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

Line Spectrum of H-atom

The spectrum of H-atom is observed as discontinuous line spectra. The different lines observed in H-spectrum were classified into different series and named after their discoverers.

Rydberg gave an empirical formula to calculate wavelength, which is applicable to all series.

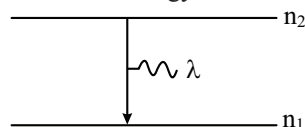
$$\frac{1}{\lambda} = R_H \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$$

$R_H = 109677 \text{ cm}^{-1}$ Rydberg's constant.

n_1 and n_2 are number of orbits involved.

Explanation of Hydrogen Spectrum using Bohr's Model

When electron in an excited atom comes back from higher energy level (n_2) to lower energy level (n_1) then it emits a photon, having energy equal to difference in energy levels.



$$h\nu = \Delta E = E_{n_2} - E_{n_1}$$

$$h\nu = \frac{-2\pi^2mk^2e^4Z^2}{n_2^2h^2} - \left(\frac{-2\pi^2mk^2e^4Z^2}{n_1^2h^2} \right)$$

$$h\nu = \frac{2\pi mk^2e^4Z^2}{h^2} \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$$

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

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

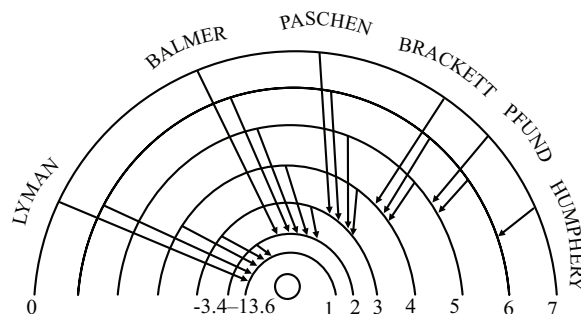
The theoretical value is very close to observed value.

∴ Bohr's model provides theoretical explanation of H-spectrum.

Wavelength or wave no. of any line of any one electron species can be calculated as:

$$\frac{1}{\lambda} = R_H Z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right], \quad \frac{hc}{\lambda} = \Delta E$$

Different Series in Hydrogen Spectrum



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

Key Points

First line / Starting line / Initial line (λ_{\max} and ν_{\min})

Last line / limiting line / Series limit (λ_{\min} and ν_{\max})

First line of any series = α line

Second line of any series = β line

Third line of any series = γ line

Total no. of emission lines between n_2 & $n_1 = \frac{(n_2 - n_1)(n_2 - n_1 + 1)}{2}$

For transition from any orbit 'n' to ground state (i.e. $n = 1$),

total no. of emission lines = $\frac{n(n-1)}{2}$

Key Note

- ❖ In case of single isolated atom if electron make transition from n^{th} state to the ground state then max. number of spectral lines observed = $(n - 1)$.

SPECTRA LINES OF HYDROGEN ATOM

Lyman Series

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

- ❖ $\frac{1}{\lambda} = R_H \left[\frac{1}{1^2} - \frac{1}{n_2^2} \right]$ where $n_2 > 1$ always.
- ❖ The wavelength of marginal line = $\frac{n_1^2}{R_H}$ for all series. So for

$$\text{Lyman series } \lambda = \frac{1}{R_H}.$$

- ❖ 1st line of lyman series = $2 \rightarrow 1$
- ❖ IInd line of lyman series = $3 \rightarrow 1$
- ❖ Last line of lyman series = $\infty \rightarrow 1$
- ❖ First line of any spectral series is the longest (λ_{\max}) line.
- ❖ Last line of any spectral series is the shortest (λ_{\min}) line.

Series limit: It is the last line of any spectral series.

Wave no. of Ist line of Lyman series

$$= \frac{1}{\lambda} = \bar{\nu} = R_H \times 1^2 \left(\frac{1}{1^2} - \frac{1}{2^2} \right)$$

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

$$\bar{\nu} = \frac{R_H \times 3}{4} = \frac{3R_H}{4}$$

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

Wave no. of last line of Lyman series

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

Balmer Series

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

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

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

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

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

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

Paschen Series

- (a) It is the third series of H-spectrum.
- (b) It was found out in infrared region by Paschen.
- (c) It has $n_1 = 3$ and $n_2 = 4, 5, 6, \dots$
- (d) The wavelength of marginal line of Paschen series

$$\frac{n_1^2}{R_H} = \frac{3^2}{R_H} = \frac{9}{R_H}.$$

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

Brackett Series

- (a) It is fourth series of H - spectrum.
- (b) It was found out in infrared region by Brackett.
- (c) It has $n_1 = 4$ and $n_2 = 5, 6, 7, \dots$
- (d) The wavelength of marginal line of brackett series

$$= \frac{n_1^2}{R_H} = \frac{4^2}{R_H} = \frac{16}{R_H}$$

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

Pfund Series

- (a) It is fifth series of H-spectrum.
- (b) It was found out in infrared region by Pfund.
- (c) It has $n_1 = 5$ and $n_2 = 6, 7, 8, \dots$ where n_1 is ground state and n_2 is excited state.
- (d) The wavelength of marginal line of Pfund series

$$= \frac{n_1^2}{R_H} = \frac{5^2}{R_H} = \frac{25}{R_H}$$

$$(e) \frac{1}{\lambda} = R_H \left[\frac{1}{5^2} - \frac{1}{n_2^2} \right] \text{ where } n_2 > 5 \text{ always.}$$

Humphrey Series

- (a) It is the sixth series of H - spectrum.
- (b) It was found out in infrared region by Humphrey.
- (c) It has $n_1 = 6$ and $n_2 = 7, 8, 9, \dots$
- (d) The wavelength of marginal line of Humphrey series

$$= \frac{n_1^2}{R_H} = \frac{6^2}{R_H} = \frac{36}{R_H}$$

$$(e) \frac{1}{\lambda} = R_H \left[\frac{1}{6^2} - \frac{1}{n_2^2} \right] \text{ where } n_2 > 6.$$



Train Your Brain

Example 18: Calculate wavelength for 2nd line of Balmer series of He⁺ ion.

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

$n_1 = 2 ; n_2 = 4$

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

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

Example 19: The ratio of $(E_2 - E_1)$ to $(E_4 - E_3)$ for He⁺ ion is approximately equal to (where E_n is the energy of nth orbit).

- (a) 10 (b) 15
(c) 17 (d) 12

Sol. $\frac{\Delta E_{2 \rightarrow 1}}{\Delta E_{4 \rightarrow 3}} = \frac{13.6(2)^2 \left[\frac{1}{(1)^2} - \frac{1}{(2)^2} \right]}{13.6(2)^2 \left[\frac{1}{(3)^2} - \frac{1}{(4)^2} \right]} \approx 15$

Example 20: If the binding energy of 2nd excited state of a hydrogen like sample is 24 eV approximately, then the ionisation energy of the sample is approximately.

- (a) 54.4 eV/atom (b) 24 eV/atom
(c) 122.4 eV/atom (d) 216 eV/atom

Sol. $\frac{13.6(Z)^2}{(3)^2} = 24$

I.E. = $13.6(Z)^2 = (24 \times 9) = 216$ eV/atom

Example 21: If electron make transition from 7th excited state to 2nd orbit in H-atom sample, find the max. number of spectral lines observed.

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

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

Example 22: Which transition of the Hydrogen spectrum would have the same length as the Balmer transition, $n = 4$ to $n = 2$ of He⁺ spectrum?

- (a) $n_2 = 2$ to $n_1 = 1$ (b) $n_2 = 3$ to $n_1 = 1$
(c) $n_2 = 4$ to $n_1 = 2$ (d) $n_2 = 5$ to $n_1 = 3$

Sol. For He⁺ ion, we have

$\frac{1}{\lambda} = R_H Z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] = [2]^2 \left[\frac{1}{2^2} - \frac{1}{4^2} \right] \times R_H$
 $= \frac{3}{4} R_H$... (i)

Now for H atom

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

Equating equs (i) and (ii) we have

$\frac{1}{n_1^2} - \frac{1}{n_2^2} = \frac{3}{4}$

Obviously $n_1 = 1$ and $n_2 = 2$. Hence the transition $n = 2$ to $n = 1$ in hydrogen atom will have the same wavelength as the transition $n = 4$ to $n = 2$ in He⁺ species.

Example 23: The shortest wave length in H-spectrum of Lyman series when $R_H = 109678 \text{ cm}^{-1}$ is?

- (a) 1215.67 Å (b) 911.7 Å
(c) 1002.7 Å (d) 1127.30 Å

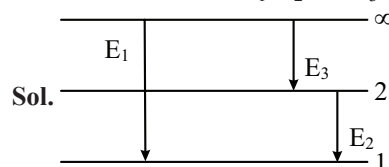
Sol. For Lyman series $n_1 = 1$

For shortest 'λ' of Lyman series, the energy difference in two levels showing transition should be maximum (i.e. $n_2 = \infty$).

$\frac{1}{\lambda} = R_H \left[\frac{1}{1^2} - \frac{1}{\infty^2} \right] = 109678 \text{ cm}^{-1}$

$\therefore \lambda = 9.117 \times 10^{-8} = 911.7 \text{ Å}$

Example 24: Let ν_1 be the frequency of series limit of lyman series, ν_2 be the frequency of 1st line of lyman series, ν_3 be the frequency of series limit of Balmer series. Then find relation between ν_1 , ν_2 and ν_3 .



$E_1 = E_2 + E_3$
 $\Rightarrow h\nu_1 = h\nu_2 + h\nu_3$
 $\Rightarrow \nu_1 = \nu_2 + \nu_3$



Concept Application

14. Which electronic transition in the He⁺ spectrum would have the same wavelength as the first Lyman transition of hydrogen?

- (a) ($n = 4$ to $n = 1$) (b) ($n = 4$ to $n = 2$)
(c) ($n = 3$ to $n = 2$) (d) ($n = 2$ to $n = 2$)

15. At what atomic number would a transition from $n = 2$ to $n = 1$ energy level result in emission of photon of $\lambda = 3 \times 10^{-8} \text{ m}$?

- (a) ($Z = 1$) (b) ($Z = 2$)
(c) ($Z = 3$) (d) ($Z = 4$)

16. The energy of hydrogen atom in its ground state is -13.6 eV. The energy of the level corresponding to $n = 5$ is:
 (a) -0.54 eV (b) -5.40 eV
 (c) -0.85 eV (d) -2.72 eV
17. The wavelength of a spectral line for an electronic transition is inversely proportional to:
 (a) Number of electrons undergoing transition.
 (b) The nuclear charge of the atom.
 (c) The velocity of an electron undergoing transition.
 (d) The difference in the energy involved in the transition.

DUAL NATURE OF MATTER (De-Broglie HYPOTHESIS)

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

Derivation of de-Broglie Relationship

For a photon,

$$E = \frac{hc}{\lambda} \quad \dots(i)$$

$$E = mc^2 \quad \dots(ii)$$

$$mc^2 = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{h}{mc} = \frac{h}{p}$$

He concluded that as electromagnetic radiation have some associated mass or associated momentum, in the same way every moving particle of mass ' m ' and velocity ' v ' is associated with waves and these associated waves are known as matter waves or de-Broglie's waves.

$$\lambda = h / mv = h / p$$

Derivation of Bohr's postulate of quantisation of angular momentum from de-Broglie's Equations: According to de-Broglie moving electron is associated with waves which must be completely in phase and therefore only those orbits are possible where circumference of the orbit is integral multiple of λ i.e. $2\pi r = n\lambda$, where n is the no. of waves.

$$2\pi r = \frac{nh}{mv} \Rightarrow mvr = \frac{nh}{2\pi}$$

From the above expression it can be commented that **number of waves in a shell in a complete revolution = shell no.**

❖ **Calculation of de-Broglie wavelength if K.E. of the particle is E :**

$$E = \frac{1}{2}mv^2 \Rightarrow 2E = mv^2$$

$$2mE = m^2 v^2 = p^2 \Rightarrow p = \sqrt{2mE}$$

$$\frac{h}{\lambda_{dB}} = \sqrt{2mE} \Rightarrow \lambda_{dB} = \frac{h}{\sqrt{2mE}}$$

If a charged particle at rest (having charge ' q ') is accelerated by potential difference ' V ' volt then:

$$\lambda_{dB} = \frac{h}{\sqrt{2mqV}}$$

$$\lambda_{dB} = \sqrt{\frac{150}{V}} \text{ \AA} \quad (\text{Only for electron})$$



Train Your Brain

Example 25: Calculate λ_{dB} of electron have K.E. 3eV .

$$\text{Sol. } \lambda_{dB} = \sqrt{\frac{150}{\text{K.E.}}} = \sqrt{\frac{150}{3}} = \sqrt{50} \text{ \AA} = 7.07 \text{ \AA}$$

Example 26: Calculate the wavelength of a moving electron having 4.55×10^{-25} J of kinetic energy.

$$\text{Sol. Kinetic energy} = \left(\frac{1}{2}mv^2\right) = 4.55 \times 10^{-25} \text{ J}$$

$$\therefore \lambda = \frac{h}{\sqrt{2 \times m \times \text{K.E.}}} = \frac{6.626 \times 10^{-34}}{\sqrt{2 \times 9.11 \times 10^{-31} \times 4.55 \times 10^{-25}}}$$

$$\text{or } \lambda = \frac{6.626 \times 10^{-34}}{\sqrt{2 \times 9.11 \times 10^{-31} \times 4.55 \times 10^{-25}}} = 7.28 \times 10^{-7} \text{ meter}$$



Concept Application

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

- (a) $\sqrt{\frac{150}{V}} \text{ \AA}$ (b) $\frac{0.286}{\sqrt{V}} \text{ \AA}$
 (c) $\frac{0.101}{\sqrt{V}} \text{ \AA}$ (d) $\frac{0.983}{\sqrt{V}} \text{ \AA}$

19. What possibly can be the ratio of the de-Broglie wavelengths for two electrons each having zero initial energy and accelerated through 50 volts and 200 volts?
 (a) 3 : 10 (b) 10 : 3 (c) 1 : 2 (d) 2 : 1

HEISENBERG'S UNCERTAINTY PRINCIPLE

The exact position and momentum of a fast moving microscopic particle cannot be calculated precisely at the same moment of time. If Δx is the error in the measurement of position of the

particle and if Δp is the error in the measurement of momentum of the particle, then:

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

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

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

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

This is because of a principle of optics that if a light of wavelength ' λ ' is used to locate the position of a particle then minimum error in the position measurement will be $\pm \lambda$ amount.

i.e. $\Delta x = \pm \lambda$

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

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

To make $\Delta x \rightarrow 0$, $\lambda \rightarrow 0$ a photon of very small wavelength i.e., high energy is required to locate it.

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

$$\Delta p \cdot \Delta x \geq \frac{h}{4\pi} \quad (\text{Multiplied \& divided by } \Delta t)$$

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

$$\left(\frac{\Delta p}{\Delta t} = \text{rate of change in momentum} = F \right)$$

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

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

$\Delta E \longrightarrow$ uncertainty in energy

$\Delta t \longrightarrow$ uncertainty in time

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

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

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



Train Your Brain

Example 27: A golf ball has a mass of 40 g, and a speed of 45 m/s. If the speed can be measured within accuracy of 2%, calculate the uncertainty in the position.

Sol. The uncertainty in the speed is 2%,

$$\text{i.e., } 45 \times \frac{2}{100} = 0.9 \text{ m s}^{-1}. \text{ Using the equation}$$

$$\Delta x = \frac{h}{4\pi m \Delta v} = \frac{6.626 \times 10^{-34}}{4 \times 3.14 \times 40 \times 10^{-3} (0.9 \text{ m s}^{-1})}$$

$$= 1.46 \times 10^{-33} \text{ m}$$

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

Example 28: The uncertainty in measuring speed of a particle is zero. Uncertainty in measuring its position will be

- (a) Zero (b) $\frac{h}{4\pi}$
 (c) $\frac{h}{4\pi m}$ (d) Infinite

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

$$\text{or } \Delta x = \infty \text{ as } \Delta v = 0$$

Example 29: The mass of a particle is 10^{-10} g and its diameter is 10^{-4} cm. If its speed is 10^{-6} cm/s with 0.0001% uncertainty in measurement, the minimum uncertainty in its position is

- (a) 5.28×10^{-8} m (b) 5.28×10^{-7}
 (c) 5.28×10^{-6} m (d) 5.28×10^{-9} m

$$\text{Sol. } m = 10^{-10} \text{ g or } m = 10^{-13} \text{ kg}$$

$$\Delta v = 10^{-6} \times 10^{-2} \times 0.0001 \times 10^{-2} \text{ m/s} = 10^{-14} \text{ m/s}$$

According to Heisenberg's Uncertainty Principle

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

$$\Delta x = \frac{6.626 \times 10^{-34}}{4 \times 3.14 \times 10^{-13} \times 10^{-14}} \text{ m or } \Delta x = 5.28 \times 10^{-8} \text{ m}$$



Concept Application

- 20.** The uncertainty in the momentum of an electron is $1.0 \times 10^{-5} \text{ kg ms}^{-1}$. The uncertainty in its position will be: ($h = 6.626 \times 10^{-34} \text{ Js}$)
 (a) $1.05 \times 10^{-28} \text{ m}$ (b) $1.05 \times 10^{-26} \text{ m}$
 (c) $5.27 \times 10^{-30} \text{ m}$ (d) $5.25 \times 10^{-28} \text{ m}$

- 21.** If uncertainty in position and momentum of a particle is numerically equal, then the minimum uncertainty in speed of the particle is

- (a) $\sqrt{\frac{h}{2\pi}}$ (b) $\frac{1}{2m} \sqrt{\frac{h}{\pi}}$
 (c) $\sqrt{\frac{h}{\pi}}$ (d) $\frac{1}{m} \sqrt{\frac{h}{\pi}}$

22. Uncertainty in the position of an electron (mass = 9.1×10^{-31} kg) moving with a velocity 300 m/s, accurate up to 0.001 %, will be ($h = 6.3 \times 10^{-34}$ Js)

- (a) 5.76×10^{-2} m (b) 1.92×10^{-2} m
(c) 3.84×10^{-2} m (d) 19.2×10^{-2} m

THE QUANTUM/WAVE MECHANICAL MODEL

- Quantum mechanics is a theoretical science that deals with the study of 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 mechanical model of atom is the picture of structure of the atom, which emerges from the application of the Schrödinger equation to atoms.
- For a particle whose energy does not vary with time, the Schrodinger equation may be written as

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

- where \hat{H} = Hamiltonian or Total energy operator, Ψ = wave function

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

where x, y and z are Cartesian Co-ordinates, m = mass of the electron,

E = Total energy of the electron, V = P.E. of the electron,

Ψ = Wave function of the electron

- For a given system for which V and m are known, we can use the Schrödinger equation to obtain value of E (the allowed energies of the particle) & Ψ (the wave function).

- For H-atom, P.E. (V) = $-\frac{Ke^2}{r}$

- Schrodinger's wave equation becomes

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} + \frac{8\pi^2 m \left(E + \frac{Ke^2}{r} \right)}{h^2} \Psi = 0$$

- The wave function itself has no physical meaning, but Ψ^2 is a probability density and for this to be the case, Ψ must have certain properties:

- It must be finite for all values of x;
- It can only have one value for any value of x;
- And $\frac{d\Psi}{dx}$ must vary continuously as x varies.

- Ψ must be continuous, have a continuous slope, be single-valued, & be square integrable.
- The results (solutions) of wave equation are
 - The wave function is a solution of the Schrodinger equation and describes the behavior of an electron in region of space called the atomic orbital.

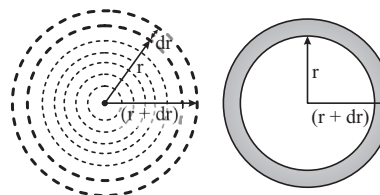
- We can find energy values that are associated with particular wave functions.
- The quantization of energy levels arises naturally from the Schrodinger equation.
- A wave function Ψ is a mathematical function that contains detailed information about the behavior of an electron.
- An atomic wave function consists of a radial component, R (r), and an angular component, A (β, ϕ).
- The region of space defined by a wave function is called an atomic orbital.

Born Interpretation of Wave Equation

- A principal tenet of quantum mechanics is that the wave function contains all the dynamic information about the system it describes.
- In the words of Born:** If the wave function of a particle has the value Ψ at some point x, then probability of finding the particle between x and (x + dx) is proportional to $|\Psi|^2 dx$.
- "For a three dimensional wave function of a particle, if the wave function of a particle has the value Ψ at some point, then probability of finding a particle in a small volume (dV) around that point is $|\Psi|^2 dV$ ".
- The wave function Ψ is a probability amplitude that means its square modulus ($|\Psi|^2$) is a probability density.**
- The physical significance of Ψ is difficult to understand, but $|\Psi|^2$ has a clear physical significance of being the probability density (probability per unit volume) of the location of particle.

Radial Probability Function

- Radial probability distribution function = $R^2 dV$.
(where R = radial wave function)
- In order to find the value of dV, the entire space of the electron orbital around the nucleus is supposed to be divided into small imaginary concentric shells of very small thickness dr, each.



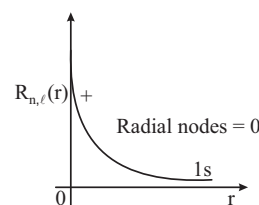
RADIAL WAVE FUNCTION FOR H-LIKE ATOMS

- $R_{n,\ell} = \text{Constant} \times \text{polynomial} \times \text{Exponential}$.

(1) $R_{n,\ell}(r)$ v/s r plots:

(i) 1s-orbital:

$$R_{1,0} = 2 \left(\frac{Z}{a_0} \right)^{3/2} \times 1 \times e^{-Zr/a_0}$$



❖ 1s - orbital has a finite value of $R_{n,\ell}(r)$ at nucleus.

(ii) 2s-orbital:

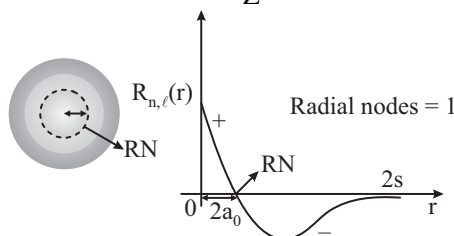
$$R_{2,0} = \left(\frac{Z}{a_0}\right)^{3/2} \frac{1}{2\sqrt{2}} \times \left(2 - \frac{Zr}{a_0}\right) \times e^{-Zr/2a_0}$$

(a) If $2 > \frac{Zr}{a_0}$, then $R_{2,0}$ is +ve.

(b) If $\frac{Zr}{a_0} > 2$, then $R_{2,0}$ is -ve.

(c) If $\frac{Zr}{a_0} = 2$, then $R_{2,0}$ is 0.

At Radial node, $r = \frac{2a_0}{Z}$

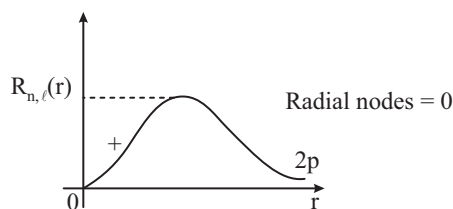


2s-orbital has a finite value of $R_{n,\ell}(r)$ at nucleus.

2s-orbital wave function also decays exponentially but its decay is slower than 1s-orbital.

(iii) 2p-subshell:

$$R_{2,1} = \left(\frac{Z}{a_0}\right)^{3/2} \frac{1}{2\sqrt{6}} \times \left(\frac{Zr}{a_0}\right) \times e^{-Zr/2a_0}$$

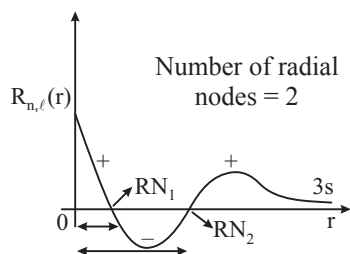


2p - orbital has zero value of $R_{n,\ell}(r)$ at nucleus.

2p - orbital has a maxima in the $R_{n,\ell}(r)$ v/s r plot.

(iv) 3s-orbital:

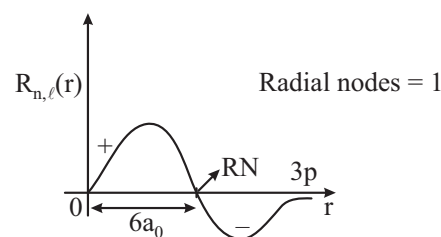
$$R_{3,0} = \left(\frac{Z}{a_0}\right)^{3/2} \frac{2}{81\sqrt{3}} \times \left(27 - 18\frac{Zr}{a_0} + \frac{2Z^2r^2}{a_0^2}\right) \times e^{-Zr/3a_0}$$



3s - orbital has a finite value of $R_{n,\ell}(r)$ at nucleus.

(v) 3p-subshell:

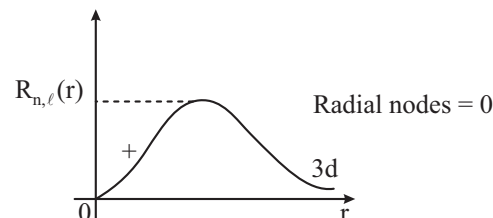
$$R_{3,1} = \left(\frac{Z}{a_0}\right)^{3/2} \frac{4}{81\sqrt{6}} \times \left(6\frac{Zr}{a_0} - \frac{Z^2r^2}{a_0^2}\right) \times e^{-Zr/3a_0}$$



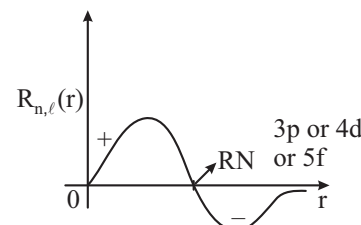
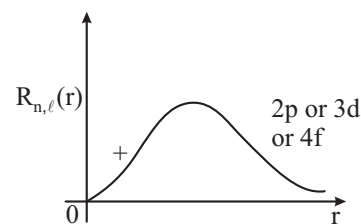
3p - orbital has zero value of $R_{n,\ell}(r)$ at nucleus.

(vi) 3d-subshell:

$$R_{3,2} = \left(\frac{Z}{a_0}\right)^{3/2} \frac{4}{81\sqrt{30}} \times \frac{Z^2r^2}{a_0^2} \times e^{-Zr/3a_0}$$



3d - orbital has zero value of $R_{n,\ell}(r)$ at the nucleus.

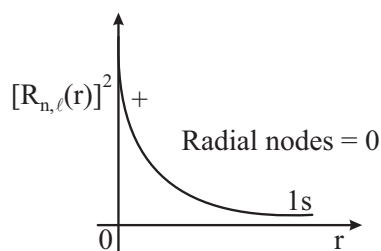


- ❖ For all orbitals other than s-orbital, $R_{n,\ell}(r) = 0$ at the nucleus.
- ❖ For all 1s - orbitals, $R_{n,\ell}(r)$ is always positive.
- ❖ For the first orbital of other types (i.e. 2p, 3d, 4f etc), $R_{n,\ell}(r)$ is +ve everywhere except at the origin.
- ❖ For the second orbital of a given type (i.e. 2s, 3p, 4d, 5f etc.), $R_{n,\ell}(r)$ may be +ve or -ve but the radial wave function has only 1 sign change, i.e. they have 1 radial node.
- ❖ For the third orbital of a given type (i.e. 3s, 4p, 5d, 6f etc.), $R_{n,\ell}(r)$ may have 2 sign changes i.e. they have 2 radial nodes.

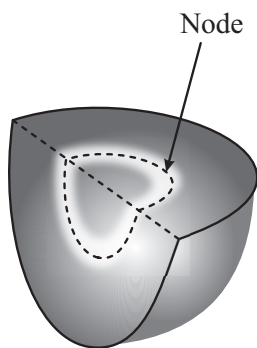
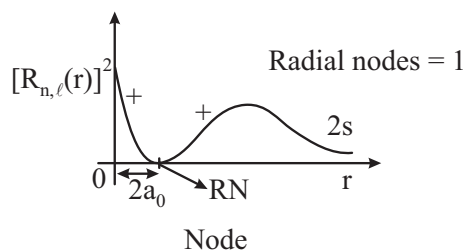
(2) $[R_{n,\ell}(r)]^2$ v/s r plots:

$[R_{n,\ell}(r)]^2$ would always be +ve, irrespective of the sign of $R_{n,\ell}(r)$ for a given value of r . R^2 represents the probability density of finding electron at a particular point in space.

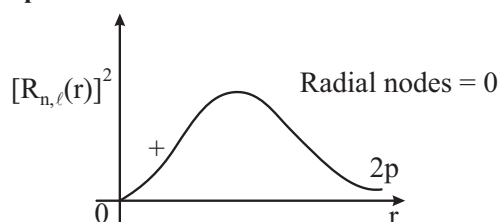
(i) 1s – orbital:



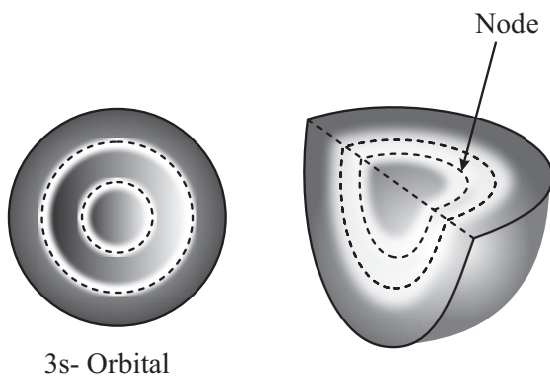
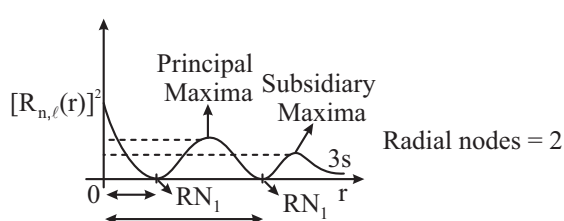
(ii) 2s – orbital:



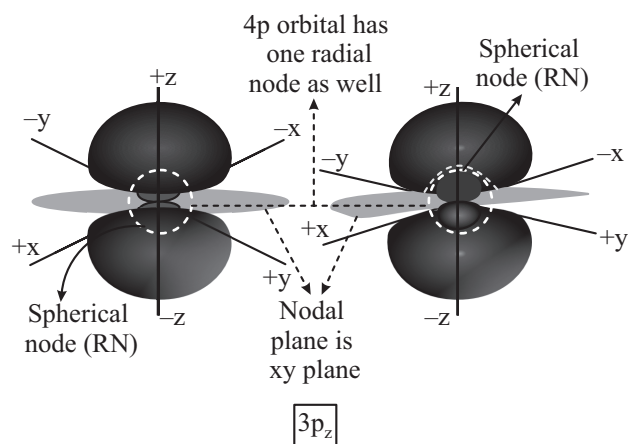
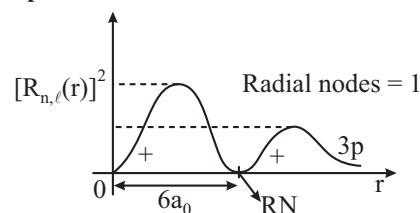
(iii) 2p – subshell:



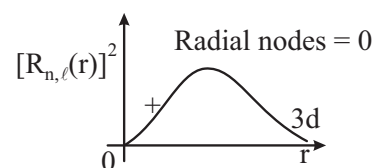
(iv) 3s –orbital:



(v) 3p-subshell:



(vi) 3d-subshell:



Key Note

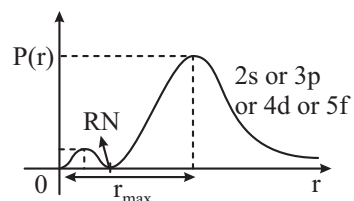
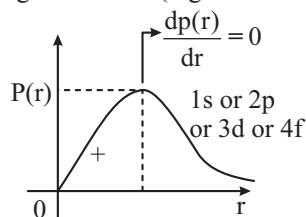
- ❖ First maxima is higher than second and second is higher than third.
- ❖ $R_{n,l}(r)$ v/s r plot, R^2 v/s r plot & $4\pi r^2 R^2$ v/s r plot are all same for '2p' orbital, '3d' orbital, '4f' orbital etc.

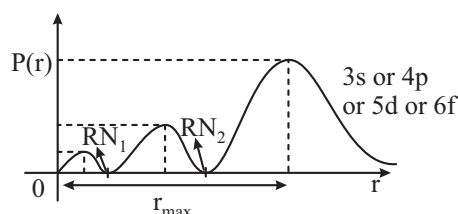
(3) $4\pi r^2 [R_{n,l}(r)]^2$ v/s r plots:

- ❖ Radial distribution function or radial probability distribution function (RPDF)

$$= p(r) dr = 4\pi r^2 [R_{n,l}(r)]^2 dr$$

The radial distribution is the probability function of choice to determine the most likely radius to find the electron for a given orbital (regardless of its direction).





Train Your Brain

Example 30: The Schrodinger wave equation for hydrogen atom is

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

Where a_0 is Bohr's radius. If the radial node in 2s be at r , then find r in terms of a_0 .

Sol. Ψ_{2s}^2 = Probability of finding electron within 2s sphere

$$\Psi_{2s}^2 = 0 \text{ at node}$$

$$\therefore \left(2 - \frac{r}{a_0} \right)^2 = 0 \Rightarrow \left(2 - \frac{r}{a_0} \right) = 0 \Rightarrow 2 = \frac{r}{a_0} \Rightarrow r = 2a_0$$



Concept Application

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

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

where $\sigma = \frac{Zr}{a_0}$ and $a_0 = 0.529 \text{ \AA}$; Z = atomic number,

r = radial distance from nucleus.

Find the distance (in \AA) of radial node of orbital from the nucleus.

24. The correct time independent Schrödinger's wave equation for an electron with E as total energy and V as potential energy is :

$$(a) \frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} + \frac{8\pi^2}{mh^2} (E - V) \Psi = 0$$

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

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

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

QUANTUM NUMBER

As we know to search a particular person in this world 4 things are needed:

1. Country to which the person belongs.
2. The city in that country where the person is residing.
3. The area in that city.
4. House number.

Similarly to locate the position of an electron in the atom 4 identification number are required and these identification number are called as quantum numbers.

1. Principal quantum number (n) \rightarrow Shell (Orbit)
2. Azimuthal quantum number (l) \rightarrow Sub shell
3. Magnetic quantum number (m) \rightarrow Orbital
4. Spin quantum number (s) \rightarrow Spin of e^-

1. Principal quantum number:

It represents the name, size and energy of the shell to which e^- belongs.

- ❖ The value of n lies between 1 to ∞ .
i.e. $n = 1, 2, 3, 4, \dots, \infty$ corresponding name of shells are K, L, M, N, O, \dots
- ❖ Greater the value of n , greater is the distance from the nucleus.

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

$$r_1 < r_2 < r_3 < r_4 < r_5 \dots$$

- ❖ Greater the value of n , greater is the energy of shell.

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

$$E_1 < E_2 < E_3 < E_4 \dots$$

- ❖ The angular momentum of a revolving electron is $mvr = \frac{nh}{2\pi}$
Where n = Principal quantum number.
- ❖ The number of electrons in a particular shell is equal to $2n^2$.

2. Azimuthal quantum number / Angular quantum number / Secondary quantum number / Subsidiary quantum number: Represented by ' l '

- ❖ It represents the shape of the subshell and orbital angular momentum.
- ❖ Value of l between 0 to $(n - 1)$.
i.e. $l = 0, 1, 2, \dots, (n - 1)$.

$$l = 0 \text{ (s Subshell)}$$

$$l = 1 \text{ (p Subshell)}$$

$$l = 2 \text{ (d Subshell)}$$

$$l = 3 \text{ (f Subshell)}$$

- ❖ If $n = 1$ then $l = 0 \Rightarrow 1s$ i.e. in $n = 1$ shell, only one subshell 's' is present.

If $n = 2$ then $l = 0, 1 \Rightarrow 2s, 2p$ i.e. in $n = 2$ shell, two subshell 's' & 'p' are present.

If $n = 3$ then $l = 0, 1, 2 \Rightarrow 3s, 3p, 3d$ i.e. in $n = 3$ shell, three subshell 's', 'p' & 'd' are present.

If $n = 4$ then $\ell = 0, 1, 2, 3 \Rightarrow 4s, 4p, 4d, 4f$ i.e. in $n = 4$ shell, four subshell 's', 'p', 'd' & 'f' are present.

- ❖ If the value of n is same then the order of energy of the various subshell will be:

$$s < p < d < f$$

$$4s < 4p < 4d < 4f, \quad 3s < 3p < 3d, \quad 2s < 2p$$

- ❖ If value of ℓ is same but value of n is different then the order of energy will be:

$$1s < 2s < 3s < 4s < 5s < 6s$$

$$3d < 4d < 5d < 6d$$

$$4p < 5p < 6p$$

- ❖ The orbital angular momentum = $\sqrt{\ell(\ell+1)} \frac{h}{2\pi}$ or $\sqrt{\ell(\ell+1)}\hbar \left\{ \because \hbar = \frac{h}{2\pi} \right\}$

Orbital angular momentum : For s subshell = 0

$$\text{For p Subshell} = \sqrt{2} \frac{h}{2\pi} \text{ or } \sqrt{2}\hbar.$$

- ❖ The number of electron in a particular subshell is equal to $2(2\ell + 1)$.

for s subshell number of electrons = $2 e^-$

for p subshell number of electrons = $6 e^-$

for d subshell number of electrons = $10 e^-$

for f subshell number of electrons = $14 e^-$

- ❖ Shape of the subshell:

s \rightarrow spherical

p \rightarrow dumb bell shape

d \rightarrow double dumb bell shape

f \rightarrow complex shape

3. Magnetic quantum number /Orientation quantum number

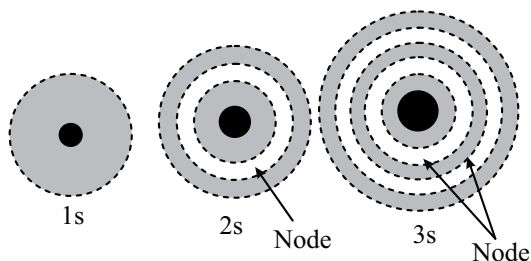
(m): It represents the shape of different orbitals and the orientation of electron cloud (orbital).

Under the influence of magnetic field each subshell is further subdivided into orbitals (The electron cloud is known as orbital). Magnetic quantum number describe these different distribution of electron clouds.

Value of m = all integral value from $-\ell$ to $+\ell$ including zero. i.e. Value of $m = -\ell, \dots, 0, \dots, +\ell$

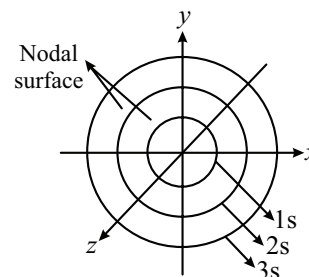
Case-I: If $\ell = 0$ then $m = 0$ it implies that s subshell has only one orbital called as "s orbital".

Shapes of s-orbitals: The s-orbitals are spherically symmetrical about the nucleus, i.e., the probability of finding ns electron is same in all directions from the nucleus. The size of the orbital depends on the value of principal quantum number, there is one spherically symmetrical orbital. The 1s orbital is smaller than 2s-orbital and 2s-orbital is smaller than 3s, but all are spherical in shape as shown in figure.



Although the s-orbitals belonging to different shells are spherically symmetrical, yet they differ in certain respects as explained below:

- The probability of 1s electron is found to be maximum near the nucleus and decreases as the distance from the nucleus increases. In case of 2s electrons, the probability is again maximum near the nucleus and then decreases to zero and increases again and then decreases as the distance from the nucleus increases. The intermediate region (a spherical shell) where the probability is zero is called a nodal surface or simply node. Thus, 2s-orbital differs from 1s-orbital in having one node within it. Similarly, 3s orbital has two nodes. In general, any ns orbital has $(n-1)$ nodes.
- The size and energy of the s-orbital increases as the principal quantum number increases, i.e., the size and energy of s-orbital increases in the order $1s < 2s < 3s \dots$



The s orbital of higher energy levels are also symmetrically spherical and can be represented as follows:

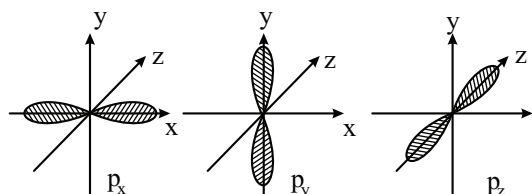
Case-II: If $\ell = 1$ (p - subshell) then $m = -1, 0, 1$

It implies that, p subshell have three orbitals called as p_x, p_y and p_z .

Shape of p-orbitals: There are three p-orbitals, commonly referred to as p_x, p_y and p_z . These three p-orbitals, possess equivalent energy. They, however, differ in their direction & distribution of the charge.

These three p-orbitals are situated at right angle to one another and are directed along x, y and z axis (figure).

Each p orbital has dumb bell shape (2 lobes which are separated from each other by a point of zero probability called nodal point or node or nucleus).

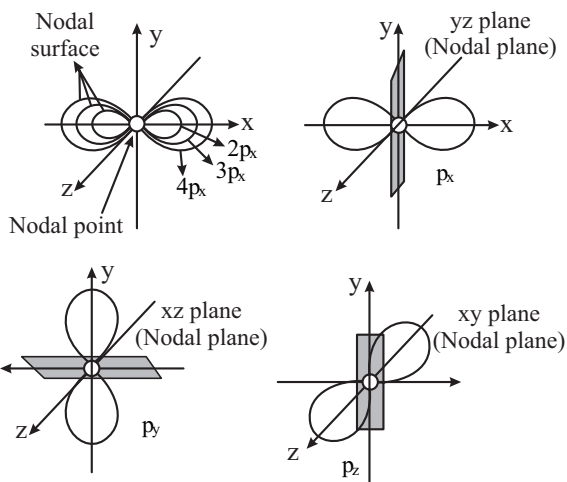


The two lobes of each orbital are separated by a plane of zero electron density called nodal plane.

Each p orbital of higher energy level are also dumb bell shape but they have spherical nodal surface.

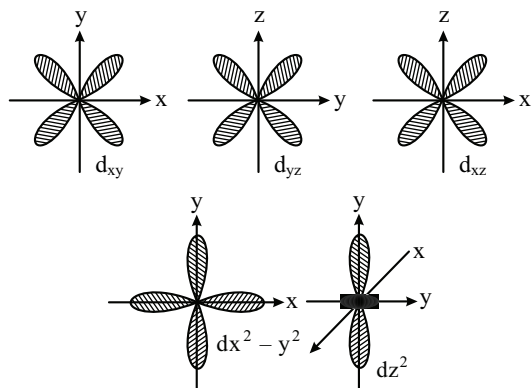
Nodal surface:	Orbital	No. of spherical nodes
	2 p_x	0
	3 p_x	1
	4 p_x	2
	np_x	$(n - 2)$

Nodal Plane:	Orbital	Nodal plane
	p_x	yz plane
	p_y	xz plane
	p_z	xy plane

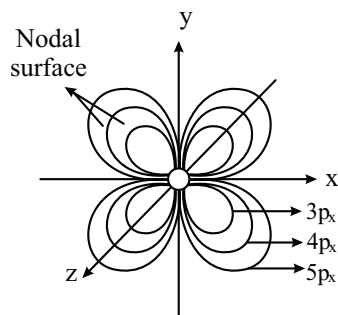


Case-III: When $\ell = 2$, 'm' has five values $-2, -1, 0, +1, +2$. It implies that d subshell of any energy shell has five orbitals. All the five orbitals are not identical in shape. Four of the d orbitals $d_{xy}, d_{yz}, d_{xz}, d_{x^2-y^2}$ contain four lobes while fifth orbital d_{z^2} consists of only two lobes. The lobes d_{xy} orbital lie between x and y axis. Similar is the case for d_{yz} and d_{xz} . Four lobes of $d_{x^2-y^2}$ orbital are lying along x and y axis while the two lobes of d_{z^2} orbital are lying along z axis and contain a ring of negative charge surrounding the nucleus in xy plane. Geometry of d orbital is Double Dumb bell.

Shape of d-orbitals: It implies that d subshell has 5 orbitals i.e. five electron cloud and can be represented as follows.



Each d-orbital of higher energy level are also double dumb bell shaped but they have spherical nodal surface.



(i) Nodal Point $\rightarrow 1$

(ii) Nodal Surface $\rightarrow 3d_{xy} \rightarrow 0$; Nodal surface
 $4d_{xy} \rightarrow 1$; Nodal surface
 $5d_{xy} \rightarrow 2$; Nodal surface
 $nd_{xy} \rightarrow (n-3)$; Nodal surface

Number of nodal surface $= n - \ell - 1$

(iii) Nodal plane : $d_{xy} \rightarrow$ xz & yz nodal plane.
 $d_{xz} \rightarrow$ xy & zy nodal plane.
 $d_{yz} \rightarrow$ zx & yx nodal plane.
 $d_{x^2-y^2} \rightarrow$ two, nodal planes at angles 45° to x and y axes
 $d_{z^2} \rightarrow$ two angular nodes (nodal cones)

Note: Orbitals of d subshell are Equivalent in energy.

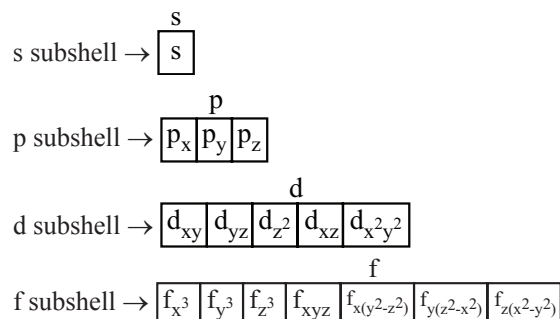
Case IV:

f subshell : When $\ell = 3$ (f subshell)

The structure of f-orbital is very complex.

The number of seven values of $m = -3, -2, -1, 0, 1, 2, 3$ for f-orbitals in f subshell show that f subshell has 7 orbitals which are equivalent in energy.

Representation of the orbitals :



4. Spin Quantum number (s):

It represents the direction of electron spin around its own axis.

❖ For clock wise spin/spin up (\uparrow) electron $\rightarrow \pm \frac{1}{2}$.

For anti-clock wise spin/spin down (\downarrow) electron $\rightarrow \mp \frac{1}{2}$.

❖ Spin angular momentum of an $e^- = \sqrt{s(s+1)} \cdot \frac{h}{2\pi}$
or $\sqrt{s(s+1)} \hbar$

❖ Each orbital can accommodate 2 electrons with opposite spin or spin paired.

Correct $\boxed{\uparrow\downarrow}$ spin paired

Wrong $\boxed{\uparrow\uparrow}$ spin paired



Train Your Brain

Example 31: For $5d_{z^2}$, calculate the value of n, l, m and s.

Sol. $n = 5, \ell = 2, m = 0, s = +\frac{1}{2}$ or $-\frac{1}{2}$

Example 32: Which of the following set of Quantum number is not possible?

- (a) $n = 3, \ell = +2, m = 0, s = +\frac{1}{2}$
 (b) $n = 3, \ell = 0, m = 0, s = -\frac{1}{2}$
 (c) $n = 3, \ell = 0, m = 1, s = +\frac{1}{2}$
 (d) $n = 3, \ell = 1, m = 0, s = -\frac{1}{2}$

Sol. For s-subshell, $\ell = 0$ then m should be 0

Example 33: The number of orbitals of g-type is

- (a) 5 (b) 7 (c) 9 (d) 11

Sol. For g-subshell, $\ell = 4$.

Therefore no. of orbital $= -\ell$ to $+\ell$.

i.e. -4 to $+4$ (including zero).

Hence in g-subshell, 9 orbitals are present.

Concept Application

25. Number of orbitals represented by $n = 3, \ell = 2$ and $m = +2$ is
 (a) 1 (b) 2 (c) 3 (d) 4
26. An electron that has the quantum numbers $n = 3$ and $m = 2$
 (a) Must have spin quantum number value, $+\frac{1}{2}$.
 (b) Must have $\ell = 2, 3$ or 4
 (c) Must have $\ell = 0, 1$ or 2
 (d) Must have $\ell = 2$
27. If an electron has spin quantum number of $+\frac{1}{2}$ and magnetic quantum number of -1 , it cannot be present in
 (a) s-orbital (b) p-orbital
 (c) d-orbital (d) f-orbital
28. In which of the following orbital, electron will be closest to the nucleus?
 (a) 6s (b) 4f (c) 5d (d) 6p
29. Possible set of electrons for which: $n = 4, \ell = 3$ and $s = +\frac{1}{2}$ is
 (a) 14 (b) 7 (c) 5 (d) 10

Rules for Filling Subshell

1. Aufbau Principle.

2. $(n + \ell)$ rule.

3. Hund's maximum spin multiplicity principle.

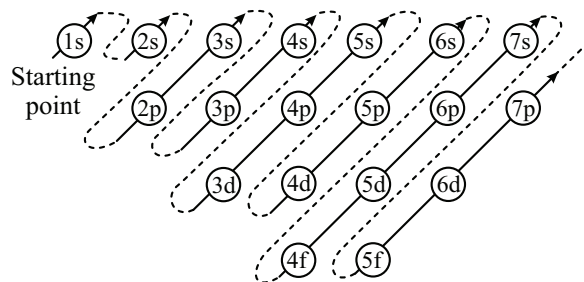
4. Pauli's exclusion principle.

1. Aufbau Principle: Aufbau is a German word and its meaning is 'Building up'.

Aufbau principle gives a sequence in which various subshell are filled up depending on the relative order of the energies of various subshell.

Principle: The subshell with minimum energy is filled up first when this subshell obtained maximum quota of electrons then the next subshell of higher energy starts filling.

The sequence in which various subshell are filled are as follows.



Electronic configuration of Atoms

$1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 3d^{10}, 4p^6, 5s^2, 4d^{10}, 5p^6, 6s^2, 4f^{14}, 5d^{10}, 6p^6, 7s^2, 5f^{14}, 6d^{10}, \dots$

For Ex.

- ${}_1\text{H} \rightarrow 1s^1$
 ${}_2\text{He} \rightarrow 1s^2$
 ${}_3\text{Li} \rightarrow 1s^2, 2s^1$
 ${}_4\text{Be} \rightarrow 1s^2, 2s^2$
 ${}_5\text{B} \rightarrow 1s^2, 2s^2, 2p^1$
 ${}_6\text{C} \rightarrow 1s^2, 2s^2, 2p^2$
 ${}_7\text{N} \rightarrow 1s^2, 2s^2, 2p^3$
 ${}_8\text{O} \rightarrow 1s^2, 2s^2, 2p^4$
 ${}_9\text{F} \rightarrow 1s^2, 2s^2, 2p^5$
 ${}_{10}\text{Ne} \rightarrow 1s^2, 2s^2, 2p^6$
 ${}_{11}\text{Na} \rightarrow 1s^2, 2s^2, 2p^6, 3s^1$
 ${}_{12}\text{Mg} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2$
 ${}_{13}\text{Al} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^1$
 ${}_{14}\text{Si} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^2$
 ${}_{15}\text{P} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^3$
 ${}_{16}\text{S} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^4$
 ${}_{17}\text{Cl} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^5$
 ${}_{18}\text{Ar} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^6$
 ${}_{19}\text{K} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^1$
 ${}_{20}\text{Ca} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2$
 ${}_{21}\text{Sc} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 3d^1$
 ${}_{22}\text{Ti} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 3d^2$
 ${}_{23}\text{V} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 3d^3$
 ${}_{24}\text{Cr} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^1, 3d^5$
 [Exception]
 ${}_{25}\text{Mn} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 3d^5$
 ${}_{26}\text{Fe} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 3d^6$

EXTRA STABILITY OF HALF-FILLED & FULLY FILLED SUBSHELLS

Symmetrical Distribution of Electrons

- ❖ It is well known that symmetry leads to stability.
- ❖ The completely filled or half-filled sub-shells have symmetrical distribution of electrons in them and are therefore more stable.

Exchange Energy

- ❖ The stabilizing effect arises whenever two or more electrons with the same spin are present in the degenerate orbitals of a sub-shell.
- ❖ These electrons tend to exchange their positions and the energy released due to this exchange is called exchange energy.
- ❖ The number of exchanges that can take place is maximum when the sub-shell is either half-filled or completely filled.
- ❖ As a result the exchange energy is maximum and so is the stability.
- ❖ You may notice that the exchange energy is at the basis of Hund's rule that electrons which enter orbitals of equal energy have parallel spins as far as possible.
- ❖ **In other words, the extra stability of half-filled and completely filled sub-shell is due to:**
- ❖ **Relatively small shielding**
- ❖ **Smaller coulombic repulsion energy**
- ❖ **Larger exchange energy**
- ❖ **Symmetrical distribution of electrons**



Train Your Brain

Example 34: Calculate the number of unpaired e^- in Cr.

Sol. $_{24}\text{Cr} \rightarrow 1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^5$

In $_{24}\text{Cr}$, $6e^-$ are unpaired.

Example 35: The number of unpaired e^- in Cr^{+3} is:

Sol. $\text{Cr}^{+3} \rightarrow 1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^3$

In Cr^{+3} , $3e^-$ are unpaired.

Example 36: The number of unpaired e^- in 3d subshell of Cr^{+3} is:

Sol. $\text{Cr}^{+3} \rightarrow 1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^3$

Therefore number of unpaired electron in 3d subshell is 3.

Example 37: The number of unpaired e^- in Fe^{+2} & Fe^{+3} are:

Sol. $\text{Fe}^{+2} \rightarrow 1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^6 = 4$ unpaired e^-

$\text{Fe}^{+3} \rightarrow 1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^5 = 5$ unpaired e^-



Concept Application

30. How many unpaired electrons are there in Ni^{+2} ion if the atomic number of Ni is 28?

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

31. Which of the following sets of quantum numbers are impossible for electrons ?

Set	n	ℓ	m	s
(i)	1	0	1	$+\frac{1}{2}$
(ii)	3	0	0	$-\frac{1}{2}$
(iii)	1	2	2	$+\frac{1}{2}$
(iv)	4	3	-3	$+\frac{1}{2}$
(v)	5	2	1	$-\frac{1}{2}$
(vi)	3	2	1	0

- (a) (i), (iii)
(b) (i), (ii), and (vi)
(c) (i), (iii), and (vi)
(d) (i), (iii), and (iv)

32. The total magnitude of spin resulting from a d^7 configuration is :

- (a) 1 (b) 2
(c) $\frac{5}{2}$ (d) $\frac{3}{2}$

33. Given is the electronic configuration of element X:

K	L	M	N
2	8	11	2

The number of electrons present with $\ell = 2$ in an atom of element X is :

- (a) 3 (b) 6
(c) 5 (d) 4

AARAMBH (SOLVED EXAMPLES)

1. The ionization energy of H-atom is 13.6 eV. The ionization energy of Li^{+2} ion will be:

(a) 13.6 eV (b) 27.2 eV
(c) 54.4 eV (d) 122.4 eV

(JEE Arjuna Chemistry M-1)

Sol. E_1 for $\text{Li}^{+2} = E_1$ for H $\times Z^2$ [for Li, $Z = 3$]
 $= 13.6 \times 9 = 122.4 \text{ eV}$

Therefore, option (d) is the correct answer.

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

(a) Electron & Proton (b) Electron & Positron
(c) Proton & Deuteron (d) Proton & Positron

(JEE Arjuna Chemistry M-1)

Sol. Positron is antiparticle of e.

Therefore, option (b) is the correct answer.

3. Wavelength of photon which have energy equal to average of energy of photons with $\lambda_1 = 4000 \text{ \AA}$ and $\lambda_2 = 6000 \text{ \AA}$ will be:

(a) 5000 \AA (b) 4800 \AA (c) 9600 \AA (d) 2400 \AA

(JEE Arjuna Chemistry M-1)

Sol. According to question $E = \frac{E_1 + E_2}{2}$

$$\text{or } \frac{hc}{\lambda} = \frac{\frac{hc}{\lambda_1} + \frac{hc}{\lambda_2}}{2}$$

$$\text{or } \frac{1}{\lambda} = \left(\frac{\frac{1}{4000} + \frac{1}{6000}}{2} \right)$$

$$\text{or } \lambda = 4800 \text{ \AA}$$

Therefore, option (b) is the correct answer.

4. The force of attraction on electron by the nucleus is directly proportional to

(a) $\frac{n^3}{Z^4}$ (b) $\frac{Z^3}{n^4}$ (c) $\frac{n^4}{Z^2}$ (d) $\frac{Z^2}{n^4}$

(JEE Arjuna Chemistry M-1)

Sol. $F = \frac{q_1 q_2}{r^2}$... (i)

$$q_1 = e^-, q_2 = ze^-$$

$$\text{and } r = 0.529 \frac{n^2}{Z} \text{ \AA}$$

Putting all these values in equation (i)

$$F = \frac{Ke^2 Z}{\left(0.529 \frac{n^2}{Z} \text{ \AA}\right)^2} \text{ or } F \propto \frac{Z^3}{n^4}$$

Therefore, option (b) is the correct answer.

5. Rydberg give the equation for all visible radiation in the hydrogen spectrum as $\lambda = \frac{kn^2}{n^2 - 4}$. The value of k in terms of Rydberg constant is:

(a) $4R$ (b) $\frac{R}{4}$ (c) $\frac{4}{R}$ (d) R

(JEE Arjuna Chemistry M-1)

Sol. According to question

$$z = 1, n_1 = 2, n_2 = n$$

$$\frac{1}{\lambda} = R_H \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] (z)^2$$

$$\text{or } \frac{1}{\lambda} = R_H \left[\frac{1}{2^2} - \frac{1}{n^2} \right] (1)^2$$

$$\text{or } \frac{1}{\lambda} = R_H \left[\frac{n^2 - 4}{4n^2} \right]$$

$$\text{or } \lambda = \frac{4n^2}{R_H (n^2 - 4)} \quad \dots (i)$$

$$\text{And also } \lambda = \frac{kn^2}{(n^2 - 4)} \quad (\text{given}) \quad \dots (ii)$$

From (i) and (ii)

$$k = \frac{4}{R_H}$$

Therefore, option (c) is the correct answer.

6. The orbital angular momentum of an electron is $\sqrt{3} \frac{h}{\pi}$.

Which of the following may be the permissible value of angular momentum of this electron revolving in unknown Bohr orbit?

(a) $\frac{h}{\pi}$ (b) $\frac{h}{2\pi}$ (c) $\frac{3h}{2\pi}$ (d) $\frac{2h}{\pi}$

(JEE Arjuna Chemistry M-1)

Sol. Orbital angular momentum $= \sqrt{l(l+1)} \frac{h}{2\pi}$

$$\text{Orbital angular momentum} = \sqrt{3} \frac{h}{\pi}$$

$$\therefore \sqrt{l(l+1)} \times \frac{h}{2\pi} = \sqrt{3} \frac{h}{\pi}$$

On Solving above equation, we get $l = -4$ and 3 (-4 not allowed as $l < 0$)

For $l = 3$, $n = 4, 5, 6$ (Possible)

Therefore possible angular momentum

$$= \frac{4h}{2\pi}, \frac{5h}{2\pi}, \frac{6h}{2\pi}, \frac{7h}{2\pi}, \dots$$

Therefore, option (d) is the correct answer.

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

(JEE Arjuna Chemistry M-1)

Sol.

$$E = \frac{240 \times 10^3}{6 \times 10^{23}} = \frac{1 \times 6.626 \times 10^{-34} \times 3 \times 10^8}{\lambda} = \lambda = 496 \text{ nm}$$

Therefore, [496] is the correct answer.

8. A sample of He^+ ions in ground state absorbs the radiation of $x\text{\AA}$. Subsequently, the sample emit radiation of 6 different wavelength. Calculate the value of x .

(JEE Arjuna Chemistry M-1)

Sol. $\frac{(n_2 - n_1)(n_2 - n_1 + 1)}{2} = 6$ given, $n_1 = 1$
 $\frac{(n-1)(n-1+1)}{2} = 6$

On solving

$$n = 4 \text{ or } n = 3$$

6 different wavelength will be obtained only from $n = 4$

$$\frac{1}{x} = R_H \times z^2 \left(\frac{1}{1^2} - \frac{1}{4^2} \right) \Rightarrow \frac{1}{x} = R_H \times z^2 \left(\frac{1}{1} - \frac{1}{16} \right)$$

$$\frac{1}{x} = R_H \times \frac{15}{16 \times 4}$$

$$\text{or } n = \frac{4}{15R_H} \text{ or } n = \frac{4}{15 \times 1.09678 \times 10^7 \text{ m}^{-1}}$$

$$\text{or } n = 243 \text{ \AA}$$

Therefore, [243] is the correct answer.

9. Through what potential difference an α -particle should be accelerated to have speed $5 \times 10^6 \text{ m/s}$.

(JEE Arjuna Chemistry M-1)

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

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

$$V = 0.26 \text{ MV}$$

Therefore, [0.26] is the correct answer.

10. Calculate the energy per quanta (in terms of 10^{-25}) of an EMR of frequency 400 MHz.

(JEE Arjuna Chemistry M-1)

Sol. $E = nh\nu$ or $\frac{E}{n} = 6.626 \times 10^{-34} \times 400 \times 10^6 \text{ J/quanta}$
 or $\frac{E}{n} = 2.65 \times 10^{-25} \text{ J/quanta}$

Therefore, [2.65] is the correct answer.

11. Calculate the wavelength (in \AA) of an EMR of energy 3.1 eV/quanta.

(JEE Arjuna Chemistry M-1)

Sol. $\frac{E}{n} = h \frac{c}{\lambda} \Rightarrow 3.1 \times 1.602 \times 10^{-19} = \frac{1 \times 6.62 \times 10^{-34} \times 3 \times 10^8}{\lambda}$

$$\text{or } \lambda = 4002.6 \text{ \AA}$$

Therefore, [4002.6] is the correct answer.

12. The energy level of a hypothetical atom for 1st, 2nd and 3rd levels are E , $4E$, $2E$ respectively. If photon of wavelength is λ emitted for a transition 3 to 1. Calculate the wavelength for transition 2 to 1 in terms of λ .

(JEE Arjuna Chemistry M-1)

Sol. Energy of photon released = $E_3 - E_1$... (i)

As we know that energy of photon is given by $= \frac{hc}{\lambda}$

where λ wavelength of photon

from (i)

$$\frac{hc}{\lambda} = E_3 - E_1 = E \Rightarrow \lambda = \frac{hc}{E} \quad \dots \text{(ii)}$$

On transition from $2 \rightarrow 1$ energy level.

Energy of photon released = $E_2 - E_1$... (iii)

Let, wavelength of photon released be λ'

$$\Rightarrow \text{Energy of photon released} = \frac{hc}{\lambda'}$$

From (iii)

$$E_2 - E_1 = \frac{hc}{\lambda'} \Rightarrow 3E = \frac{hc}{\lambda'} \Rightarrow \lambda' = \frac{hc}{3E} = \frac{1}{3} \left(\frac{hc}{E} \right)$$

$$\Rightarrow \lambda' = \frac{1}{3}(\lambda) \text{ (from (ii)) } \Rightarrow \lambda' = \frac{\lambda}{3}$$

Therefore, wavelength of photon emitted for transition

$$2 \rightarrow 1 \text{ is } \frac{\lambda}{3}.$$

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

$$\text{Na}^+, \text{Li}^+, \text{F}^-, \text{Mg}^{2+}, \text{Al}^{3+}$$

(JEE Arjuna Chemistry M-1)

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

Therefore, correct order is $\text{Na}^+ < \text{F}^- < \text{Mg}^{2+} < \text{Al}^{3+} < \text{Li}^+$.

14. If the P.E. of an electron is -6.8 eV in hydrogen atom then find

(a) K.E.

(b) E

(c) No. of orbit

(c) Radius of orbit.

(JEE Arjuna Chemistry M-1)

Sol. (a) P.E. = -2K.E.

$$-6.8 = -2\text{K.E.}$$

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

(b) E = -K.E.

$$= -3.4\text{ eV}$$

(c) Orbit = 2nd

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

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

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

$$\text{i.e. } n = 2$$

$$(d) \quad r = 0.529 \times \frac{n^2}{Z} \text{ \AA}$$

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

$$= 0.529 \times 4 \text{ \AA} = 2.12 \text{ \AA}$$

SCHOOL LEVEL PROBLEMS

SINGLE CORRECT TYPE QUESTIONS

1. In lithium nitride, the nitride ion is composed of:

(a) 7 – protons + 10 electrons
(b) 12 – protons + 5 electrons
(c) 12 – protons + 8 electrons
(d) 10 – protons + 7 electrons

(JEE Arjuna Chemistry M-1)

2. The wavelength of an emission line obtained for Li^{2+} during a electronic transition from $n_2 = 2$ to $n_1 = 1$ is: (R = Rydberg constant)

(a) $3R/4$ (b) $27R/4$
(c) $4/3R$ (d) $4/27R$

(JEE Arjuna Chemistry M-1)

3. A 100 watt bulb emits monochromatic light of wavelength 400 nm. Calculate the number of photons emitted per second by the bulb.

(a) $20.12 \times 10^{20} \text{ s}^{-1}$ (b) $2.012 \times 10^{20} \text{ s}^{-1}$
(c) $4.969 \times 10^{-19} \text{ s}^{-1}$ (d) $49.69 \times 10^{-19} \text{ s}^{-1}$

(JEE Arjuna Chemistry M-1)

4. The radius of the first orbit of hydrogen atom is $0.52 \times 10^{-8} \text{ cm}$. The radius of the first orbit of He^+ ion is

(a) $0.26 \times 10^{-8} \text{ cm}$ (b) $0.52 \times 10^{-8} \text{ cm}$
(c) $1.04 \times 10^{-8} \text{ cm}$ (d) $2.08 \times 10^{-8} \text{ cm}$

(JEE Arjuna Chemistry M-1)

5. The de-Broglie wavelength associated with particle of mass 10^{-6} kg moving with a velocity of 10 m/sec is:

(a) $6.63 \times 10^{-7} \text{ m}$ (b) $6.63 \times 10^{-16} \text{ m}$
(c) $6.63 \times 10^{-21} \text{ m}$ (d) $6.63 \times 10^{-29} \text{ m}$

(JEE Arjuna Chemistry M-1)

6. The set of quantum no. not applicable for an electron-

(a) $2, 0, 0, -\frac{1}{2}$ (b) $3, 1, -2, +\frac{1}{2}$
(c) $4, 2, -2, -\frac{1}{2}$ (d) $6, 0, 0, +\frac{1}{2}$

(JEE Arjuna Chemistry M-1)

7. The atomic numbers of elements X, Y and Z are 19, 21 and 25 respectively. The number of electrons present in the M shells of these elements follow the order.

(a) $Z > X > Y$ (b) $X > Y > Z$
(c) $Z > Y > X$ (d) $Y > Z > X$

(JEE Arjuna Chemistry M-1)

8. Light of wavelength λ shines on a metal surface with intensity X and the metal emits Y electrons per second of average energy, Z. What will happen to Y and Z if λ is doubled?

(a) Y will be double and Z will become half
(b) Y will remain same and Z will be doubled
(c) Both Y and Z will be doubled
(d) Y will be doubled but Z will remain same

(JEE Arjuna Chemistry M-1)

Directions: These questions consist of two statements each, printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.

- (a) Both Assertion and Reason are True and the Reason is a correct explanation of the Assertion.
(b) Both Assertion and Reason are True but Reason is not a correct explanation of the Assertion.
(c) Assertion is True but the Reason is False.
(d) Assertion is False but Reason is True.

9. **Assertion:** It is impossible to determine the exact position and exact momentum of an electron simultaneously.

Reason: The path of an electron in an atom is clearly defined.

(JEE Arjuna Chemistry M-1)

10. **Assertion:** In $3d_{z^2}$, the number of radial nodes is zero.

Reason: No. of radial nodes of atomic orbitals is equal to value of $(n - \ell - 1)$.

(JEE Arjuna Chemistry M-1)

MATCH THE COLUMN TYPE QUESTIONS

11. Match the following rules with their statements:

Column-I		Column-II	
A.	Hund's Rule	p.	No two electrons in an atom can have the same set of four quantum numbers.
B.	Aufbau Principle	q.	Half-filled and completely filled orbitals have extra stability
C.	Pauli Exclusion Principle	r.	Pairing of electrons in the orbitals belonging to the same subshell does not take place until each orbital is singly occupied.
D.	Heisenberg's Uncertainty principle	s.	It is impossible to determine the exact position and exact momentum of a subatomic particle simultaneously.
		t.	In the ground state of atoms, orbitals are filled in the order of their increasing energies.

- (a) A-(s); B-(r); C-(p); D-(q)
(b) A-(s); B-(p); C-(q); D-(t)
(c) A-(r); B-(q); C-(s); D-(p)
(d) A-(r); B-(t); C-(p); D-(s)

(JEE Arjuna Chemistry M-1)

12. Match the following

Column-I		Column-II	
A.	X-rays	p.	$\nu = 10^0 - 10^4 \text{ Hz}$
B.	UV	q.	$\nu = 10^{11} - 10^{13} \text{ Hz}$
C.	Long radio waves	r.	$\nu = 10^{16} \text{ Hz}$
D.	Microwave	s.	$\nu = 10^{18} \text{ Hz}$

(a) A-(s); B-(r); C-(p); D-(q)

(b) A-(q); B-(s); C-(p); D-(r)

(c) A-(r); B-(q); C-(s); D-(p)

(d) A-(s); B-(p); C-(q); D-(r)

(JEE Arjuna Chemistry M-1)

SHORT ANSWER TYPE QUESTIONS

13. Calculate the wave number and frequency of yellow radiation having wavelength 3200 Angstrom.

(JEE Arjuna Chemistry M-1)

14. For a metal, threshold frequency is $6.8 \times 10^{14} \text{ s}^{-1}$. Calculate the kinetic energy of an electron when frequency $1.0 \times 10^{15} \text{ s}^{-1}$ hits the metal.

(JEE Arjuna Chemistry M-1)

15. If an electron in a hydrogen atom is in the $n = 4$ energy level and undergoes transition to the $n = 2$ energy level, calculate the energy change and the frequency of the emitted photon using Bohr's model.

(JEE Arjuna Chemistry M-1)

16. Calculate the lowest energy of the spectral lines emitted by the hydrogen atom in the Lyman series.

(JEE Arjuna Chemistry M-1)

17. Calculate the minimum uncertainty in the position of a particle if its uncertainty in momentum is $2.0 \times 10^{-27} \text{ kg-m/s}$

(JEE Arjuna Chemistry M-1)

18. Calculate the number of electrons in atom having following quantum numbers:

(a) $n = 2, m_s = -1/2$

(b) $n = 4, l = 0$

(JEE Arjuna Chemistry M-1)

LONG ANSWER TYPE QUESTIONS

19. Explain the Pauli Exclusion Principle and Hund's Rule. How do these principles affect the filling of electron energy levels and sublevels in atoms? (JEE Arjuna Chemistry M-1)

20. (a) Calculate the velocity of the electron in the first Bohr orbit having radius a_0 . Also, calculate the de-Broglie wavelength in m.

(b) Electromagnetic radiation having a wavelength 340 nm is just sufficient to cause ionization of sodium atoms. calculate the ionization energy in kJ/mol.

(JEE Arjuna Chemistry M-1)

21. On passing electric discharge through hydrogen gas, the hydrogen molecules undergo dissociation and produce

excited hydrogen atoms. These excited atoms emit electromagnetic radiations with discrete frequencies having formula:

$$\bar{\nu} = 109677 \left[\frac{1}{n_i^2} - \frac{1}{n_f^2} \right]$$

What points of Bohr model can be used to reach this formula? Based on these points, derive the formula and explain each step along with each term.

(JEE Arjuna Chemistry M-1)

22. Describe the significance of quantum numbers (n, l, m_l , and m_s) in the quantum mechanical model of the atom. Explain how these quantum numbers define electronic states within an atom.

(JEE Arjuna Chemistry M-1)

23. A photon has wavelength 4×10^{-7} strikes on a metal surface where the work function is 1.23 eV. Determine the

(a) energy of the photon in eV

(b) the kinetic energy of the emission

(c) velocity of the photoelectron

(JEE Arjuna Chemistry M-1)

CASE STUDY BASED QUESTIONS

24. In 1909, Ernest Rutherford conducted a ground breaking experiment known as the "Rutherford gold foil experiment" to investigate the structure of the atom. At that time, J.J. Thomson's "plum pudding" model was widely accepted, suggesting that atoms were composed of a positively charged "pudding" with negatively charged electrons embedded within it. Rutherford's experiment aimed to test this model and explore the nature of atomic structure.

(JEE Arjuna Chemistry M-1)

(i) What type of particles were used in Rutherford's gold foil experiment?

(a) Electrons

(b) Neutrons

(c) Protons

(d) Alpha particles

(ii) In the Rutherford gold foil experiment, most of the alpha particles:

(a) Passed through the gold foil without any deflection.

(b) Were completely absorbed by the gold foil.

(c) Were deflected at large angles.

(d) Were deflected at small angles.

(iii) What was the primary conclusion drawn from the Rutherford experiment?

(a) Atoms consist of a positively charged nucleus.

(b) Electrons are evenly distributed throughout the atom.

(c) Atoms are mostly empty space.

(d) Electrons are larger than protons.

(iv) How did Rutherford's findings impact the development of atomic theory?

(a) They confirmed the plum pudding model.

(b) They had no impact on atomic theory.

(c) They led to the development of the Bohr model.

(d) They supported the idea of continuous matter.

DISCOVERY OF SUB ATOMIC PARTICLES, ATOMIC MODELS, NUCLEUS

1. The fraction of volume occupied by the nucleus with respect to the total volume of an atom is:
- (a) 10^{-15} (b) 10^{-5}
(c) 10^{-30} (d) 10^{-10}

(JEE Arjuna Chemistry M-1)

2. When lithium vapours were filled in the discharge tube for anode rays experiment, the anode rays were found to contain only Li^+ ions ($A = 7, Z = 3$). Therefore, each particle of anode rays contains
- (a) 1 proton only.
(b) 3 protons and 4 neutrons only.
(c) 3 protons, 4 neutrons and 2 electrons.
(d) 3 protons, 3 neutrons and 3 electrons.

(JEE Arjuna Chemistry M-1)

3. The ratio of e/m for a cathode ray:
- (a) Varies with a gas in a discharge tube.
(b) Is fixed.
(c) Varies with different electrodes.
(d) Is maximum if hydrogen is taken.

(JEE Arjuna Chemistry M-1)

4. Cathode rays have:
- (a) Mass only (b) Charge only
(c) No mass and no charge (d) Mass and charge both

(JEE Arjuna Chemistry M-1)

5. Which is the correct statement about proton?
- (a) It is a nucleus of deuterium.
(b) It is an ionised hydrogen molecule.
(c) It is an ionised hydrogen atom.
(d) It is an α -particle.

(JEE Arjuna Chemistry M-1)

6. Rutherford's experiment on scattering of α -particles showed for the first time that the atom has:
- (a) Electrons (b) Protons
(c) Neutrons (d) Nucleus

(JEE Arjuna Chemistry M-1)

7. When alpha particles are sent through a thin metal foil, most of them go straight through the foil because:
- (a) Alpha particles are much heavier than electrons.
(b) Alpha particles are positively charged.
(c) Most part of the atom is empty space.
(d) Alpha particles move with very high velocity.

(JEE Arjuna Chemistry M-1)

8. 1 mole of diatomic gas A_2 contain 32 and 36 moles of electrons and neutrons respectively. The representation of the element is

- (a) ${}_{32}A^{68}$ (b) ${}_{16}A^{34}$
(c) ${}_{16}A^{18}$ (d) ${}_{32}A^{36}$

(JEE Arjuna Chemistry M-1)

9. Nucleons are:
- (a) Protons and neutrons.
(b) Neutrons and electrons.
(c) Protons and electrons.
(d) Protons, neutrons and electrons.

(JEE Arjuna Chemistry M-1)

10. The discovery of neutron came very late because:

- (a) It is present in nucleus.
(b) It is a fundamental particle.
(c) It does not move.
(d) It does not carry any charge.

(JEE Arjuna Chemistry M-1)

11. Atomic number of an element represents:

- (a) Number of neutrons in the nucleus.
(b) Atomic mass of an element.
(c) Valency of an element.
(d) Number of protons in the nucleus.

(JEE Arjuna Chemistry M-1)

12. The highest value of e/m of anode rays has been observed when the discharge tube is filled with:

- (a) Dinitrogen (b) Dioxygen
(c) Dihydrogen (d) Helium

(JEE Arjuna Chemistry M-1)

QUANTUM THEORY OF LIGHT & PHOTOELECTRIC EFFECT

13. The MRI (magnetic resonance imaging) body scanners used in hospitals operate with 400 MHz radio frequency. The wavelength corresponding to this radio frequency is:

- (a) 0.75 m (b) 0.75 cm
(c) 1.5 m (d) 2 cm

(JEE Arjuna Chemistry M-1)

14. Electromagnetic radiations of wavelength 242 nm is just sufficient to ionise Sodium atom. Then the ionisation energy of Sodium in kJ mole^{-1} is:

- (a) 494.65 (b) 400
(c) 247 (d) 600

(JEE Arjuna Chemistry M-1)

15. A bulb of 40 W is producing a light of wavelength 620 nm with 80% of efficiency then the number of photons emitted by the bulb in 20 seconds are ($1\text{ eV} = 1.6 \times 10^{-19}\text{ J}$, $hc = 12400\text{ eV \AA}$):

(a) 2×10^{18} (b) 10^{18}
(c) 10^{21} (d) 2×10^{21}

(JEE Arjuna Chemistry M-1)

16. Light of wavelength λ falls on metal having work function hc/λ_0 . Photoelectric effect will take place only if:

(a) $\lambda \geq \lambda_0$ (b) $\lambda \geq 2\lambda_0$
(c) $\lambda \leq \lambda_0$ (d) $\lambda \leq \lambda_0/2$

(JEE Arjuna Chemistry M-1)

17. A light whose frequency is equal to $6 \times 10^{14}\text{ Hz}$ is incident on a metal whose work function is 2 eV ($h = 6.626 \times 10^{-34}\text{ Js}$, $1\text{ eV} = 1.6 \times 10^{-19}\text{ J}$). The maximum energy of electrons emitted will be:

(a) 2.49 eV (b) 4.49 eV
(c) 0.49 eV (d) 5.49 eV

(JEE Arjuna Chemistry M-1)

18. A 600 W mercury lamp emits monochromatic radiation of wavelength 331.3 nm. How many photons are emitted from the lamp per second?

($h = 6.626 \times 10^{-34}\text{ Js}$, velocity of light = $3 \times 10^8\text{ ms}^{-1}$)

(a) 1×10^{19} (b) 1×10^{20}
(c) 1×10^{21} (d) 1×10^{23}

(JEE Arjuna Chemistry M-1)

19. Photoelectric effect can be explained by assuming that light:

(a) Is a form of transverse wave.
(b) Is a form of longitudinal wave.
(c) Can be polarised.
(d) Consists of quanta.

(JEE Arjuna Chemistry M-1)

20. When the frequency of light incident on a metallic plate is doubled of threshold frequency, the K.E. of the emitted photoelectrons will be:

(a) Doubled
(b) Halved
(c) Increased but more than double of the previous K.E.
(d) Unchanged

(JEE Arjuna Chemistry M-1)

21. A photon of 300 nm is absorbed by a gas and then emits two photons. One photon has a wavelength 496 nm then the wavelength of second photon is:

(a) 759 (b) 857 (c) 957 (d) 657

(JEE Arjuna Chemistry M-1)

BOHR MODEL

22. Which is the correct relationship:

(a) $E_1\text{ of H} = 1/2 E_2\text{ of He}^+ = 1/3 E_3\text{ of Li}^{2+} = 1/4 E_4\text{ of Be}^{3+}$

(b) $E_1\text{ (H)} = E_2\text{ (He}^+) = E_3\text{ (Li}^{2+}) = E_4\text{ (Be}^{3+})$

(c) $E_1\text{ (H)} = 2E_2\text{ (He}^+) = 3E_3\text{ (Li}^{2+}) = 4E_4\text{ (Be}^{3+})$

(d) No relation

(JEE Arjuna Chemistry M-1)

23. If velocity of an electron in 1st orbit of H atom is V, what will be the velocity of electron in 3rd orbit of Li^{2+} ?

(a) V (b) $V/3$
(c) $3V$ (d) $9V$

(JEE Arjuna Chemistry M-1)

24. In a certain electronic transition in the hydrogen atoms from an initial state (1) to a final state (2), the difference in the orbit radius ($r_1 - r_2$) is 24 times the first Bohr radius. Identify the transition:

(a) $5 \rightarrow 1$ (b) $25 \rightarrow 1$
(c) $8 \rightarrow 3$ (d) $6 \rightarrow 5$

(JEE Arjuna Chemistry M-1)

25. S_1 : Potential energy of the two opposite charge system increases with the decrease in distance.

S_2 : When an electron make transition from higher orbit to lower orbit, it's kinetic energy increases.

S_3 : When an electron make transition from lower energy to higher energy state its potential energy increases.

S_4 : 11 eV photon can free an electron from the 1st excited state of He^+ -ion.

(a) T T T T (b) F T T F
(c) T F F T (d) F F F F

(JEE Arjuna Chemistry M-1)

26. Energy of Bohr orbit:

(a) Increases as we move away from the nucleus.
(b) Decreases as we move away from the nucleus.
(c) Remains the same as we move away from the nucleus.
(d) None of the above.

(JEE Arjuna Chemistry M-1)

27. The radius of the first orbit of H-atom is r. Then, the radius of the first orbit of Li^{2+} will be:

(a) $r/9$ (b) $r/3$
(c) $3r$ (d) $9r$

(JEE Arjuna Chemistry M-1)

28. According to Bohr theory, the angular momentum for an electron of 5th orbit is:

(a) $5 h/\pi$ (b) $2.5 h/\pi$
(c) $5 \pi/h$ (d) $25 h/\pi$

(JEE Arjuna Chemistry M-1)

29. Which of the following electron transitions in hydrogen atom will require largest amount of energy?

(a) from $n = 1$ to $n = 2$ (b) from $n = 2$ to $n = 3$
(c) from $n = \infty$ to $n = 1$ (d) from $n = 3$ to $n = 5$

(JEE Arjuna Chemistry M-1)

30. $E_n = -313.6/n^2$ kcal/mol. If the value of $E = -34.84$ kcal/mol, to which value does 'n' correspond?
 (a) 4 (b) 3 (c) 2 (d) 1

(JEE Arjuna Chemistry M-1)

31. Bohr's atomic model suggests that
 (a) Electrons have a particles as well as wave character
 (b) Atomic spectrum of atom should contain only five lines
 (c) Electron on H-atom can have only certain values of angular momentum
 (d) All of the above

(JEE Arjuna Chemistry M-1)

32. In Bohr's model of the hydrogen atom, let r , v and E represent the orbit radius, speed of an electron and the total energy of the electron, respectively. Which of following relation is proportional to the orbit number n ?
 (a) $v \cdot r$ (b) r/E
 (c) r/v (d) $r \cdot E$

(JEE Arjuna Chemistry M-1)

33. An electron in H-atom in its ground state absorbs 1.50 times as much as energy as the minimum required for its escape (13.6 eV) from the atom. Thus K.E. given to emitted electron is:
 (a) 13.6 eV (b) 20.4 eV
 (c) 34.0 eV (d) 6.8 eV

(JEE Arjuna Chemistry M-1)

34. Bohr's theory is not valid for the species:
 (a) H atom (b) He^+ ion
 (c) Li^+ ion (d) Li^{2+} ion

(JEE Arjuna Chemistry M-1)

35. If r_1 is the radius of the first orbit of hydrogen atom, then the radii of second, third and fourth orbitals in terms of r_1 are:
 (a) r_1^2, r_1^3, r_1^4 (b) $8r_1, 27r_1, 64r_1$
 (c) $4r_1, 9r_1, 16r_1$ (d) $2r_1, 6r_1, 8r_1$

(JEE Arjuna Chemistry M-1)

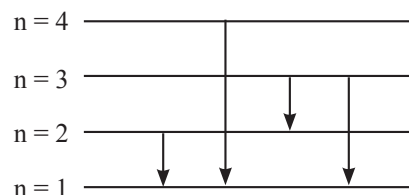
SPECTRUM

36. In a sample of H-atom electrons make transition from 5th excited state upto ground state, producing all possible types of photons, then number of lines in infrared region are:
 (a) 4 (b) 5 (c) 6 (d) 3
- (JEE Arjuna Chemistry M-1)
37. Total no. of lines in Lyman series of H-spectrum will be (where n = no. of orbits):
 (a) n (b) $n - 1$
 (c) $n - 2$ (d) $n(n + 1)$
- (JEE Arjuna Chemistry M-1)
38. No. of visible lines when an electron returns from 5th orbit upto ground state in H-spectrum:
 (a) 5 (b) 4

- (c) 3 (d) 10

(JEE Arjuna Chemistry M-1)

39. Suppose that a hypothetical atom gives a red, green, blue and violet line spectrum among given transition. Which jump according to figure would give off the red spectral line?



- (a) $3 \rightarrow 1$ (b) $2 \rightarrow 1$
 (c) $4 \rightarrow 1$ (d) $3 \rightarrow 2$

(JEE Arjuna Chemistry M-1)

40. The difference between the wave number of 1st line of Balmer series and last line of Paschen series for Li^{2+} ion is:

- (a) $\frac{R}{36}$ (b) $\frac{5R}{36}$ (c) $4R$ (d) $\frac{R}{4}$

(JEE Arjuna Chemistry M-1)

41. The spectral lines corresponding to the radiation emitted by an electron jumping from higher orbits to first orbit belong to:
 (a) Paschen series (b) Balmer series
 (c) Lyman series (d) None of these

(JEE Arjuna Chemistry M-1)

42. For the Paschen series, the value of n_1 and n_2 in the expression

$$\Delta E = R_H \times hc \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] \text{ is:}$$

- (a) $n_1 = 1, n_2 = 2, 3, 4, \dots$ (b) $n_1 = 2, n_2 = 3, 4, 5, \dots$
 (c) $n_1 = 3, n_2 = 4, 5, 6, \dots$ (d) $n_1 = 4, n_2 = 5, 6, 7, \dots$

(JEE Arjuna Chemistry M-1)

43. If the series limit of wavelength of the Lyman series for the hydrogen atoms is 912 \AA , then the series limit of wavelength for the Balmer series of the hydrogen atom is:

- (a) 912 \AA (b) $912 \times 2 \text{ \AA}$
 (c) $912 \times 4 \text{ \AA}$ (d) $912/2 \text{ \AA}$

(JEE Arjuna Chemistry M-1)

44. The shortest λ for the Lyman series of hydrogen atom is ... (Given $R_H = 109678 \text{ cm}^{-1}$)

- (a) 911.7 \AA (b) 700 \AA
 (c) 600 \AA (d) 811 \AA

(JEE Arjuna Chemistry M-1)

45. The frequency of first line of Balmer series in hydrogen atom is ν_0 . The frequency of corresponding line emitted by singly ionised helium atom is:

- (a) $2\nu_0$ (b) $4\nu_0$
 (c) $\nu_0/2$ (d) $\nu_0/4$

(JEE Arjuna Chemistry M-1)

46. Which of the following statement is not true?
- Lyman spectral series of hydrogen atom lies in the ultraviolet region of electromagnetic radiation.
 - Balmer spectral series of hydrogen atom lies in the visible region of electromagnetic radiation.
 - Paschen spectral series of hydrogen atom lies in the visible region of electromagnetic radiation.
 - Brackett spectral series of hydrogen atom lies in the infrared region of electromagnetic radiation.

(JEE Arjuna Chemistry M-1)

47. The first emission line of Balmer series in H-spectrum has the wave number equal to:

- $\frac{9R_H}{400} \text{ cm}^{-1}$
- $\frac{7R_H}{144} \text{ cm}^{-1}$
- $\frac{3R_H}{4} \text{ cm}^{-1}$
- $\frac{5R_H}{36} \text{ cm}^{-1}$

(JEE Arjuna Chemistry M-1)

48. When an electron de-excites from higher orbit in H-atom, only two radiations are emitted out one in Paschen series and one in Lyman series. The wavelength of radiation emitted out in Lyman series is:

- $\frac{8R}{9}$
- $\frac{3R}{4}$
- $\frac{4}{3R}$
- $\frac{9}{8R}$

(JEE Arjuna Chemistry M-1)

DE-BROGLIE WAVELENGTH AND HEISENBERG UNCERTAINTY PRINCIPLE

49. The momentum of a photon of wavelength 6626 nm will be
- $10^{-28} \text{ kg ms}^{-1}$
 - $10^{-25} \text{ kg ms}^{-1}$
 - $10^{-31} \text{ kg ms}^{-1}$
 - Zero

(JEE Arjuna Chemistry M-1)

50. de-Broglie wavelength of electron in second orbit of Li^{2+} ion will be equal to de-Broglie wavelength of electron in:
- $n = 3$ of H-atom
 - $n = 4$ of C^{5+} ion
 - $n = 6$ of Be^{3+} ion
 - $n = 3$ of He^+ ion

(JEE Arjuna Chemistry M-1)

51. de-Broglie equation describes the relationship of wavelength associated with the motion of an electron and its:
- Mass
 - Energy
 - Momentum
 - Charge

(JEE Arjuna Chemistry M-1)

52. A body of mass 'x' kg is moving with velocity of 100 m sec^{-1} . It's de-Broglie wavelength is $6.62 \times 10^{-35} \text{ m}$. Hence 'x' is ($h = 6.62 \times 10^{-34} \text{ J sec}$):
- 0.25 kg
 - 0.15 kg
 - 0.2 kg
 - 0.1 kg

(JEE Arjuna Chemistry M-1)

53. The wavelengths of electron waves in two orbits is 3 : 5. The ratio of kinetic energy of electrons will be:
- 25 : 9
 - 5 : 3
 - 9 : 25
 - 3 : 5

(JEE Arjuna Chemistry M-1)

54. A ball of mass 200 g is moving with a velocity of 10 m sec^{-1} . If the error in measurement of velocity is 0.1%, the uncertainty in its position is:
- $3.3 \times 10^{-31} \text{ m}$
 - $3.3 \times 10^{-27} \text{ m}$
 - $5.3 \times 10^{-25} \text{ m}$
 - $2.64 \times 10^{-32} \text{ m}$

(JEE Arjuna Chemistry M-1)

55. If the radius of first Bohr orbit is x, then de-Broglie wavelength of electron in 3rd orbit is nearly:
- $2\pi x$
 - $6\pi x$
 - $9x$
 - $x/3$

(JEE Arjuna Chemistry M-1)

56. Which of the following particles moving with same velocity would be associated with smallest de-Broglie wavelength?
- Dihydrogen molecule
 - Dioxygen molecule
 - Helium molecule
 - Dinitrogen molecule

(JEE Arjuna Chemistry M-1)

QUANTUM NUMBERS & ELECTRONIC CONFIGURATION

57. Spin magnetic moment of X^{n+} ($Z = 26$) is $\sqrt{24}$ B.M. Hence number of unpaired electrons and value of n respectively are:
- 4, 2
 - 2, 4
 - 3, 1
 - 0, 2

(JEE Arjuna Chemistry M-1)

58. Which of the following ions has the maximum number of unpaired d-electrons?
- Zn^{2+}
 - Mn^{2+}
 - Ni^{3+}
 - Cu^+

(JEE Arjuna Chemistry M-1)

59. Consider the ground state of Cr atom ($Z = 24$). The numbers of electrons with the azimuthal quantum numbers, $\ell = 1$ and 2 are, respectively:
- 16 and 5
 - 12 and 5
 - 16 and 4
 - 12 and 4

(JEE Arjuna Chemistry M-1)

60. The orbital angular momentum of an electron in 2s-orbital is:
- $+\frac{1}{2} \frac{h}{2\pi}$
 - Zero
 - $\frac{h}{2\pi}$
 - $\sqrt{2} \frac{h}{2\pi}$

(JEE Arjuna Chemistry M-1)

61. The possible value of ℓ and m for the last electron in the Cl^- ion are:

(a) 1 and 2 (b) 2 and +1
(c) 3 and -1 (d) 1 and -1

(JEE Arjuna Chemistry M-1)

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

(a) 0 (b) $\sqrt{6} \frac{h}{2\pi}$
(c) $\sqrt{2} \frac{h}{2\pi}$ (d) $3 \left(\frac{h}{2\pi} \right)$

(JEE Arjuna Chemistry M-1)

QUANTUM MECHANICAL MODEL OF ATOM, SCHRODINGER WAVE EQUATION AND ORBITAL CONCEPT

63. The maximum radial probability in 1s-orbital occurs at a distance when: [r_0 = Bohr radius]

(a) $r = r_0$ (b) $r = 2r_0$
(c) $r = \frac{r_0}{2}$ (d) $2r = \frac{r_0}{2}$

(JEE Arjuna Chemistry M-1)

64. The maximum probability of finding an electron in the d_{xy} orbital is :

(a) Along the x-axis.
(b) Along the y-axis.
(c) At an angle of 45° from the x and y axis.
(d) At an angle of 90° from the x and y axis.

(JEE Arjuna Chemistry M-1)

65. $3p_y$ orbital has.....nodal plane :

(a) XY (b) YZ
(c) ZX (d) All of these

(JEE Arjuna Chemistry M-1)

66. A 3p-orbital has:

(a) Two non-spherical nodes.
(b) Two spherical nodes.
(c) One spherical and one non spherical nodes.
(d) One spherical and two non spherical nodes.

(JEE Arjuna Chemistry M-1)

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

(a) Particle only.
(b) Wave only.
(c) Particle and wave nature simultaneous.
(d) Sometimes waves and sometimes particle.

(JEE Arjuna Chemistry M-1)

68. Consider the following statements:

(A) Electron density in the XY plane in $3d_{x^2-y^2}$ orbital is zero.
(B) Electron density in the XY plane in $3d_{z^2}$ orbital is zero.
(C) 2s orbital has one spherical nodal.
(D) For $2p_z$ orbital, XY is the nodal plane.

Which of these are incorrect statements?

(a) A & C (b) D & C
(c) Only B (d) A, B

(JEE Arjuna Chemistry M-1)

69. Which of the following d-orbitals has dough-nut shape ?

(a) d_{xy} (b) d_{yz}
(c) $d_{x^2-y^2}$ (d) d_{z^2}

(JEE Arjuna Chemistry M-1)

70. The permissible solution to the Schrodinger wave equation gave an idea of only quantum numbers.

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

(JEE Arjuna Chemistry M-1)

1. A light source of wavelength (λ) illuminates a metal and ejects photo-electrons with $(K.E.)_{\max} = 1 \text{ eV}$.

Another light source of wavelength $\lambda/3$, ejects photo-electrons from same metal with $(K.E.)_{\max} = 5 \text{ eV}$.

Find the value of work function?

- (a) 1 eV (b) 2 eV
(c) 0.5 eV (d) None of these

(JEE Arjuna Chemistry M-1)

2. A single electron species in energy level (orbit number n) with energy X was provided with excess of energy so that it jumps to higher energy level with energy Y . If it can emit radiations of six different wavelengths on de-excitation between these two energy levels, then the correct relation is

- (a) $\frac{X}{Y} = (n-1)^2$ (b) $\frac{X}{Y} = 1 + \frac{3}{n}$
(c) $\sqrt{\frac{X}{Y}} = 1 + \frac{3}{n}$ (d) $\frac{X}{Y} = 1 + \frac{n}{3}$

(JEE Arjuna Chemistry M-1)

3. The potential energy of the electron present in the ground state of Be^{3+} ion is represented by:

- (a) $+\frac{e^2}{\pi \epsilon_0 r}$ (b) $-\frac{e}{\pi \epsilon_0 r}$
(c) $-\frac{e^2}{\pi \epsilon_0 r^2}$ (d) $-\frac{e^2}{\pi \epsilon_0 r}$

(JEE Arjuna Chemistry M-1)

4. Which transition in Li^{2+} would have the same wavelength as the $2 \rightarrow 4$ transition in He^+ ion?

- (a) $4 \rightarrow 2$ (b) $1 \rightarrow 2$
(c) $3 \rightarrow 6$ (d) $6 \rightarrow 2$

(JEE Arjuna Chemistry M-1)

5. Let ν_1 be the frequency of the series limit of the Lyman series, ν_2 be the frequency of the first line of the Lyman series, and ν_3 be the frequency of the series limit of the Balmer series:

- (a) $\nu_1 - \nu_2 = \nu_3$
(b) $\nu_2 - \nu_1 = \nu_3$
(c) $\nu_3 = 1/2 (\nu_1 - \nu_3)$
(d) $\nu_1 + \nu_2 = \nu_3$

(JEE Arjuna Chemistry M-1)

6. In a sample of H-atoms, electrons de-excite from a level ' n ' to 1. The total number of lines belonging to Balmer series are two. If the electrons are ionised from level ' n ' by photons

of energy 13 eV. Then the kinetic energy of the ejected photoelectrons will be :

- (a) 12.15 eV (b) 11.49 eV
(c) 12.46 eV (d) 12.63 eV

(JEE Arjuna Chemistry M-1)

7. A particle X moving with a certain velocity has a de-Broglie wave length of 1 \AA . If particle Y has a mass of 25% that of X and velocity 75% that of X, de-Broglie wave length of Y will be:

- (a) 3 \AA (b) 5.33 \AA
(c) 6.88 \AA (d) 48 \AA

(JEE Arjuna Chemistry M-1)

8. The ratio of the de-Broglie wavelength of a proton and α -particles will be 1 : 2 if their:

- (a) Velocity are in the ratio 1 : 8.
(b) Velocity are in the ratio 8 : 1.
(c) Kinetic energy are in the ratio 1 : 64.
(d) Kinetic energy are in the ratio 1 : 256.

(JEE Arjuna Chemistry M-1)

9. Consider an electron in the n^{th} orbit of a hydrogen atom in the Bohr model. The circumference of the orbit can be expressed in terms of the de-Broglie wavelength (λ) of the electron as:

- (a) $(0.529) n\lambda$ (b) $\sqrt{n}\lambda$
(c) $(13.6) \lambda$ (d) $n\lambda$

(JEE Arjuna Chemistry M-1)

10. In case of $d_{x^2-y^2}$ orbital:

- (a) Probability of finding the electron along x-axis is zero.
(b) Probability of finding the electron along y-axis is zero.
(c) Probability of finding the electron is maximum along x and y-axis.
(d) Probability of finding the electron is zero in x-y plane.

(JEE Arjuna Chemistry M-1)

11. The value of the spin magnetic moment of a particular ion is 2.83 Bohr magneton. The ion is:

- (a) Fe^{2+} (b) Ni^{2+} (c) Mn^{2+} (d) Co^{3+}

(JEE Arjuna Chemistry M-1)

12. If n and ℓ are respectively the principal and azimuthal quantum numbers, then the expression for calculating the total number of electrons in any orbit is:

$$(a) \sum_{\ell=1}^{\ell=n} 2(2\ell+1) \quad (b) \sum_{\ell=1}^{\ell=n-1} 2(2\ell+1)$$

$$(c) \sum_{\ell=0}^{\ell=n+1} 2(2\ell+1) \quad (d) \sum_{\ell=0}^{\ell=n-1} 2(2\ell+1)$$

(JEE Arjuna Chemistry M-1)

13. The difference in Bohr's radius of H atom for $(n+1)$ and n^{th} radius is equal to $(n-1)^{\text{th}}$ Bohr radius. The value of n is:

(a) 3 (b) 2 (c) 4 (d) 5

(JEE Arjuna Chemistry M-1)

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

(a) $\lambda_e > \lambda_p = \lambda_\alpha$ (b) $\lambda_p = \lambda_\alpha > \lambda_e$
(c) $\lambda_p > \lambda_e > \lambda_\alpha$ (d) $\lambda_\alpha > \lambda_e \gg \lambda_p$

(JEE Arjuna Chemistry M-1)

15. In an atom, two electrons move around the nucleus in circular orbits of radii R and 4R respectively. The ratio of the time taken by them to complete one revolution is:

(a) 1 : 4 (b) 4 : 1
(c) 1 : 8 (d) 8 : 7

(JEE Arjuna Chemistry M-1)

16. An electron is continuously accelerated in vacuum tube under applied potential difference. Calculate the change in kinetic energy if de-Broglie wavelength is decreased by 2%

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

(JEE Arjuna Chemistry M-1)

17. The difference in angular momentum associated with the electron in two successive orbits of hydrogen atom is:

(a) h/π (b) $h/2\pi$
(c) $h/2$ (d) $(n-1)h/2\pi$

(JEE Arjuna Chemistry M-1)

18. An α -particle is accelerated from rest through a potential difference of 6.0 V. Its de-Broglie wavelength is:

(a) 5 Å (b) 4.15 pm
(c) 414.6 Å (d) 5 nm

(JEE Arjuna Chemistry M-1)

19. A photon of 2.55 eV is emitted out by an electronic transition in hydrogen atom. The change in de-Broglie wavelength of the electron is:

(a) 3.32 Å (b) 4.13 Å
(c) 6.64 Å (d) 9.96 Å

(JEE Arjuna Chemistry M-1)

20. An electron that has the quantum numbers $n=3$ and $m=2$:

(a) Must have $l=3, 4$ or 5
(b) Must have $l=2, 3$ or 4

(c) Must have $l=0, 1$ or 2

(d) Must have $l=2$

(JEE Arjuna Chemistry M-1)

21. Electronic configuration of an element is $1s^2, 2s^1, 2p^2$. It is:

(a) Ground state configuration of B ($Z=5$).
(b) Excited state configuration of B.
(c) Ground state configuration of C^+ ion ($Z=6$).
(d) Impossible configuration.

(JEE Arjuna Chemistry M-1)

22. What is the most probable distance of a 1s-electron in a He^+ ion? The wave function for 1s-orbital is given by

$$\psi = \sqrt{\left(\frac{Z^3}{\pi a_0^3}\right)} e^{-Zr/a_0}, \text{ where } a_0 = \text{radius of first Bohr's orbit}$$

in H-atom = 52.9 pm.

(a) 52.9 pm (b) 13.25 pm
(c) 6.61 pm (d) 26.45 pm

(JEE Arjuna Chemistry M-1)

23. The dissociation energy of H_2 is 429.0 kJ/mol. If H_2 is dissociated by illumination with radiation of wavelength 270.0 nm, then what percentage of radiant energy will be converted into kinetic energy? ($h=6.6 \times 10^{-34}$ Js, $N_A=6 \times 10^{23}$)

(a) 1.25% (b) 3.26%
(c) 2.46% (d) 7.5%

(JEE Arjuna Chemistry M-1)

24. The magnitude of the orbital angular momentum of an electron is given by $L = \sqrt{5} h/\pi$. How many orbitals of this kind are possible, belonging to an orbit?

(a) 4 (b) 5 (c) 11 (d) 9

(JEE Arjuna Chemistry M-1)

25. How many electrons can fit into the orbitals that comprise the 3rd quantum shell, $n=3$?

(a) 2 (b) 8 (c) 18 (d) 32

(JEE Arjuna Chemistry M-1)

26. Which of the following sets of quantum numbers is correct for an electron in 4f-orbital?

(a) $n=4, l=3, m=+4, s=+1/2$
(b) $n=4, l=4, m=-4, s=-1/2$
(c) $n=4, l=3, m=+1, s=+1/2$
(d) $n=3, l=2, m=-2, s=+1/2$

(JEE Arjuna Chemistry M-1)

27. In any subshell, the maximum number of electrons having same values of spin quantum number is:

(a) $\sqrt{l(l+1)}$ (b) $l+2$
(c) $2l+1$ (d) $4l+2$

(JEE Arjuna Chemistry M-1)

28. Total number of values of "m" for $n = 4$ is:
 (a) 8 (b) 16 (c) 12 (d) 20
(JEE Arjuna Chemistry M-1)
29. The electronic configuration of an atom/ion can be defined by which of the following?
 (a) Aufbau principle.
 (b) Pauli's exclusion principle.
 (c) Hund's rule of maximum multiplicity.
 (d) All of these.
(JEE Arjuna Chemistry M-1)
30. An ion which has 18 electrons in the outermost shell is:
 (a) K^+ (b) Cu^+ (c) Cs^+ (d) Th^{4+}
(JEE Arjuna Chemistry M-1)
31. A strong argument for the charge and particle nature of cathode rays is:
 (a) They can rotate paddle wheel.
 (b) They can propagate in vacuum.
 (c) They cast shadows.
 (d) They are deflected by electric and magnetic fields.
(JEE Arjuna Chemistry M-1)
32. The ratio of angular momentum in 3rd orbit and orbital angular momentum of 3d-orbital is:
 (a) $\sqrt{6}$ (b) $\frac{\sqrt{3}}{\sqrt{2}}$
 (c) $\frac{\sqrt{2}}{\sqrt{3}}$ (d) $\frac{1}{\sqrt{6}}$
(JEE Arjuna Chemistry M-1)
33. Which of the following statements is not correct?
 (a) The shape of an atomic orbital depends on the azimuthal quantum number.
 (b) The orientation of an atomic orbital depends on the magnetic quantum number.
 (c) The energy of an electron in an atomic orbital of multi-electron atom depends only on the principal quantum number.
 (d) All of these
(JEE Arjuna Chemistry M-1)
34. Gases begin to conduct electricity in discharge tube at low pressure because:
 (a) At low pressures, gases turn to plasma.
 (b) Colliding electrons can acquire higher kinetic energy due to increased mean free path leading to ionisation of atoms.
 (c) Atoms break up into electrons and protons.
 (d) The electrons in atoms can move freely at low pressure.
(JEE Arjuna Chemistry M-1)
35. The uncertainty in momentum of an electron is $1 \times 10^{-5} \text{ kg ms}^{-1}$. The uncertainty in its position will be ($h = 6.626 \times$

10^{-34} J.s):

- (a) $1.05 \times 10^{-28} \text{ m}$ (b) $1.05 \times 10^{-26} \text{ m}$
 (c) $5.27 \times 10^{-30} \text{ m}$ (d) $5.25 \times 10^{-28} \text{ m}$

(JEE Arjuna Chemistry M-1)

INTEGER TYPE QUESTIONS

36. Number of possible spectral lines which may be emitted in Bracket series in H atom if electrons present in 9th excited level returns to ground level, are _____.

(JEE Arjuna Chemistry M-1)

37. In a sample of H-atom, electrons make transition from 5th excited state to ground state, producing all possible types of photons, then number of lines in infrared region are _____.

(JEE Arjuna Chemistry M-1)

38. Magnetic moment of X^{3+} ion of 3d series is $\sqrt{35} \text{ BM}$. What is atomic number of X^{3+} ?

(JEE Arjuna Chemistry M-1)

39. 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

Metal	Li	Na	K	Mg	Cu	Ag	Fe	Pt	W
$\phi(\text{eV})$	2.4	2.3	2.2	3.7	4.8	4.3	4.7	6.3	4.75

(JEE Arjuna Chemistry M-1)

40. Photons of same energy were allowed to strike on two different samples of hydrogen atoms, one having each atom in ground state and other in a particular excited state of orbit number n . The photonic beams ionize the hydrogen atoms in both the samples. If the difference in maximum kinetic energy of emitted photoelectron from both the samples is 12.75 eV, then find the value of n .

(JEE Arjuna Chemistry M-1)

41. A photon having $\lambda = 960 \text{ \AA}$ causes the ionization of a nitrogen atom. Give the I.E. per mole of nitrogen in kJ.

(Use : $hc = 1240 \text{ eV} \times \text{nm}$ and $1 \frac{\text{eV}}{\text{atom}} = 96.0 \text{ kJ/mol}$.)

(JEE Arjuna Chemistry M-1)

42. The work function for a metal is 40 eV. To emit photo electrons of zero velocity from the surface of the metal the wavelength of incident light should be $x \text{ nm}$. Find value of x .

(JEE Arjuna Chemistry M-1)

43. If first ionization potential of a hypothetical atom is 16 V, then the first excitation potential [in eV] will be:

(JEE Arjuna Chemistry M-1)

44. Electrons in the H-atoms jump from some higher level upto 3rd energy level. If three spectral lines are possible for the transition, find the initial orbit of electron.

(JEE Arjuna Chemistry M-1)

45. In H-spectrum, longest wavelength of Lyman series is 120 nm and shortest wavelength of Balmer series is 360 nm. From this data, find longest wavelength [in nm] of photon, that can ionize this H-atom.
(JEE Arjuna Chemistry M-1)
46. The ionisation energy of the hydrogen atom is given to be 13.6 eV. A photon falls on a hydrogen atom which is initially in the ground state and excites it to the ($n = 4$) state. Calculate the wavelength (in nm) of the photon.
(JEE Arjuna Chemistry M-1)
47. When a certain metal was irradiated with light of frequency $4.0 \times 10^{16} \text{ s}^{-1}$, the photoelectrons emitted had three times the kinetic energy as the kinetic energy of photoelectrons emitted with the metal was irradiated with light of frequency $2.0 \times 10^{16} \text{ s}^{-1}$. Calculate the critical frequency (ν_0 in 10^6) of the metal.
(JEE Arjuna Chemistry M-1)
48. An electron in He^+ ion occupies ground state. It is excited to next higher state. The ratio of circumference of excited to ground state is _____.
(JEE Arjuna Chemistry M-1)
49. H-like species emitted a photon corresponding to the first line of Lyman series. The photon liberated a photoelectron from He^+ in ground state. The de-Broglie wavelength of the photoelectron is 2 \AA . Calculate the atomic number of H-like species.
(JEE Arjuna Chemistry M-1)
50. In a sample of hydrogen atoms, electrons jump from 10th excited state to ground state. If x are the number of different ultraviolet radiations, y are number of different visible radiations and z are number of different infrared radiations. Find the value of $z - (x + y)$.
[Assume all the Balmer lines lie within visible region]
(JEE Arjuna Chemistry M-1)

PARIKSHIT (JEE ADVANCED LEVEL)

SINGLE CORRECT TYPE QUESTIONS

1. An electron in hydrogen atom first jumps from second excited state to first excited state and then, from first excited state to ground state. Let the ratio of wavelength, momentum and energy of photons in the two cases by x , y and z , then select the wrong answers:
(a) $z = 1/x$ (b) $x = 9/4$
(c) $y = 5/27$ (d) $z = 5/27$
(JEE Arjuna Chemistry M-1)
2. A particle of $\frac{e}{m}$ ratio equal to $4 \times 10^5 \text{ coul/kg}$ is accelerated from rest through a potential difference of 20 volt. The speed of particle is:
(a) 4.0 m/s (b) 4000 km/s
(c) 4000 cm/s (d) 4000 m/s
(JEE Arjuna Chemistry M-1)
3. For a 3s-orbital, value of ψ is given by following relation :
$$\psi(3s) = \frac{1}{9\sqrt{3}} \left(\frac{1}{a_0} \right)^{3/2} (6 - 6\sigma + \sigma^2) e^{-\sigma/2}; \text{ where } \sigma = \frac{2r \cdot Z}{3a_0}$$

What is the maximum radial distance of node from nucleus?
(a) $\frac{(3 + \sqrt{3})a_0}{Z}$ (b) $\frac{a_0}{Z}$
(c) $\frac{3(3 + \sqrt{3})a_0}{2Z}$ (d) $\frac{2a_0}{Z}$
(JEE Arjuna Chemistry M-1)
4. The radial part $R(r) = \frac{1}{9\sqrt{6}a_0^{3/2}} \left(\frac{6r}{a_0} - \frac{r^2}{a_0^2} \right) e^{-r/3a_0}$ represent which orbital—
(a) 3s (b) 3d
(c) 3p (d) 2s
(JEE Arjuna Chemistry M-1)
5. The angular momentum of electron in Bohr's orbit is J . What will be the K.E. of electron in that Bohr's orbit?
(a) $\frac{1}{2} \frac{Jv}{r}$ (b) $\frac{Jv}{r}$
(c) $\frac{J^2}{2m}$ (d) $\frac{J^2}{2r}$
(JEE Arjuna Chemistry M-1)
6. Select the correct statement(s):
(a) All electromagnetic radiation travel with speed of light in vacuum.
(b) Energy of photon of UV light is lower than that of yellow light.
(c) He^+ and H have similar spectrum.
(d) The total energy of an electron in unielectronic specie is greater than zero.
(JEE Arjuna Chemistry M-1)
7. Which is **correct** statement:
(a) The difference in angular momentum associated with the electron present in consecutive orbits of H-atom is $(n-1) \frac{h}{2\pi}$.

- (b) Energy difference between energy levels will be changed if, P. E. at infinity assigned value other than zero.
 (c) Frequency of spectral line in a H-atom is in the order of $(2 \rightarrow 1) < (3 \rightarrow 1) < (4 \rightarrow 1)$.
 (d) On moving away from the nucleus, kinetic energy of electron increases.

(JEE Arjuna Chemistry M-1)

MULTIPLE CORRECT TYPE QUESTIONS

8. Which are correct statements?

- (a) Hund's rule deals with degenerate orbitals.
 (b) Pauli exclusion principal stated that only two electrons may exist in the same orbital and these electrons must have opposite spin.
 (c) In ground state of an atom, the orbitals are filled on the basis of increasing $(n + l)$ value.
 (d) The maximum number of electrons in the subshell with principal quantum number 'n' is equal to $2n^2$.

(JEE Arjuna Chemistry M-1)

9. Which statements are correct?

- (a) ψ (orbital wave function) is a mathematical function of co-ordinates of the electron.
 (b) ψ^2 represents probability density of electron at a point.
 (c) Schrodinger wave equation play same role in quantum mechanics as Newton's Law of motion do in classical mechanics.
 (d) None of these

(JEE Arjuna Chemistry M-1)

10. Choose the correct statements from among the following:

- (a) The total number of spherical nodes in an orbital are $n - l - 1$.
 (b) The total number of angular nodes in an orbital are l .
 (c) The number of maxima in an orbital is $(n - l)$.
 (d) A node is a point in space where the wave function ψ has zero amplitude.

(JEE Arjuna Chemistry M-1)

11. When photons of energy 4.25 eV strikes the surface of a metal 'A', the ejected photoelectrons have maximum kinetic energy T_A (in eV) and de-Broglie wavelength λ_A . The maximum kinetic energy of photoelectrons liberated from another metal 'B' by photons of energy 4.20 eV is T_B ($= T_A - 1.50$ eV). If the de-Broglie wave length of these photoelectrons is λ_B ($= 2\lambda_A$), then

- (a) The work function of 'A' is 2.25 eV
 (b) The work function of 'B' is 3.70 eV
 (c) $T_A = 2.00$ eV
 (d) $T_B = 2.75$ eV

(JEE Arjuna Chemistry M-1)

12. Which is/are correct for sodium atom in the ground state?

- (a) There is only one unpaired electron.
 (b) There are five pairs of electrons.
 (c) 6 electrons are of one spin and other 5 are of opposite spin.
 (d) There are ten electrons of the same spin.

(JEE Arjuna Chemistry M-1)

13. If there are only two H-atoms, each is in 3^{rd} excited state then:
 (a) Maximum number of different photons emitted is 4.
 (b) Maximum number of different photos emitted is 3.
 (c) Minimum number of different photons emitted is 1.
 (d) Minimum number of different photons emitted is 2.

(JEE Arjuna Chemistry M-1)

14. In the experiment on photoelectric effect using light having frequency greater than the threshold frequency, the photocurrent will certainly increase when:

- (a) Anode voltage is increased.
 (b) Area of cathode surface is increased.
 (c) Intensity of incident light is increased.
 (d) Distance between anode and cathode is increased.

(JEE Arjuna Chemistry M-1)

15. Which of the following statements is/are correct for an electron of quantum numbers $n = 4$ and $m = 2$?

- (a) The value of ℓ may be 2.
 (b) The value of ℓ may be 3.
 (c) The value of s may be $+1/2$.
 (d) The value of ℓ may be 0, 1, 2, 3.

(JEE Arjuna Chemistry M-1)

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

- (a) The electronic configuration of Cr is $[\text{Ar}] (3d)^5 (4s)^1$. (Atomic number of Cr = 24)
 (b) The magnetic quantum number may have negative values.
 (c) In silver atom, 23 electrons have spin of one type and 24 of the opposite type. (Atomic number of Ag = 47)
 (d) None of these

(JEE Arjuna Chemistry M-1)

COMPREHENSION BASED QUESTIONS

Comprehension (Q. 17 to 20): The wave function for an atomic orbital of single electron atom or ion is

$$\Psi(r, \theta, \phi) = \frac{2}{3} \left(\frac{Z}{3a_0} \right)^{3/2} (1 - \sigma)(12 - 8\sigma + \sigma^2) \cdot \sigma \cdot e^{-\sigma/2} \cdot \cos \theta$$

where $\sigma = \left(\frac{2Zr}{na_0} \right)$ and $a_0 = 0.529 \text{ \AA}$. All other parameters

have their usual meaning. (JEE Arjuna Chemistry M-1)

17. The number of radial and angular nodes for the orbital is, respectively,

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

(JEE Arjuna Chemistry M-1)

18. The atomic orbital should be:

- (a) 4p (b) 5p (c) 5d (d) 5f

(JEE Arjuna Chemistry M-1)

19. If θ is the angle measured from Z-axis, then the orbital should be:

- (a) p_x (b) p_y (c) p_z (d) d_{z^2}

(JEE Arjuna Chemistry M-1)

20. The maximum distance of radial node from the nucleus is:

- (a) $\frac{a_0}{Z}$ (b) $\frac{3a_0}{Z}$ (c) $\frac{6a_0}{Z}$ (d) $\frac{15a_0}{Z}$

(JEE Arjuna Chemistry M-1)

MATCH THE COLUMN TYPE QUESTIONS

21. Match Column-I with Column-II and select the correct answer using the codes given below in the lists (n, ℓ and m are respectively the principal, azimuthal and magnetic quantum no.)

Column-I		Column-II	
A.	Number of values of ℓ for an energy level (n)	p.	0, 1, 2, (n - 1)
B.	Values of ℓ for a particular type of orbit	q.	$+\ell$ to $-\ell$ through zero
C.	Number of value of m for $\ell = 2$	r.	5
D.	Values of 'm' for a particular type of orbital	s.	n

- (a) $A \rightarrow (r); B \rightarrow (p); C \rightarrow (s); D \rightarrow (q)$
 (b) $A \rightarrow (s); B \rightarrow (q); C \rightarrow (r); D \rightarrow (p)$
 (c) $A \rightarrow (s); B \rightarrow (p); C \rightarrow (r); D \rightarrow (q)$
 (d) $A \rightarrow (r); B \rightarrow (p); C \rightarrow (s); D \rightarrow (q)$

(JEE Arjuna Chemistry M-1)

22. Match the column & choose the correct option among the options given.

Column-I		Column-II	
A.	$5 \rightarrow 1$ transition in H atom	p.	spectral line in IR region
B.	$7 \rightarrow 3$ transition in H atom	q.	spectral line in visible region
C.	Last line of Balmer series in H atom	r.	spectral line in ultra violet region
D.	$4 \rightarrow 2$ transition in He^+ ion		

- (a) $A \rightarrow (r); B \rightarrow (q); C \rightarrow (r); D \rightarrow (p)$
 (b) $A \rightarrow (r); B \rightarrow (p); C \rightarrow (q); D \rightarrow (r)$
 (c) $A \rightarrow (r); B \rightarrow (r); C \rightarrow (p); D \rightarrow (r)$
 (d) $A \rightarrow (r); B \rightarrow (r); C \rightarrow (p); D \rightarrow (q)$

(JEE Arjuna Chemistry M-1)

INTEGER TYPE QUESTIONS

23. What is likely to be orbit number for a circular orbit of diameter 20 nm of the hydrogen atom if we assume Bohr orbit to be the same as that represented by the principal quantum number?

(JEE Arjuna Chemistry M-1)

24. Find the quantum number (n) corresponding to the excited state of He^+ ion if on transition to the ground state, that ion emits two photons in succession with wavelengths 108.5 and 30.4 nm

(JEE Arjuna Chemistry M-1)

25. Find the atomic number of hydrogen-like ion which has the wavelength difference between the first line of Balmer and Lyman series equal to 59.3 nm.

(JEE Arjuna Chemistry M-1)

26. The diameter of a dust particle of mass 10^{-3} gm is 2\AA .

If uncertainty in speed of this particle is $\frac{3.31}{\pi} \times 10^{-3}$ m/s,

then find minimum uncertainty in its position (in terms of 10^{-26} m).

(JEE Arjuna Chemistry M-1)

27. A hydrogen-like atom with (atomic number Z) is present in the higher excited state of quantum number n. This excited state atom can make a transition to the 1st excited state by successively emitting two photons of energies 10 eV and 17 eV, respectively. Alternatively, the atom from the same excited state can make a transition to 2nd excited state by emitting two photons of energies 4.25 eV and 5.95 eV, respectively. Find sum of Z and n.

(JEE Arjuna Chemistry M-1)

28. If a metal is exposed with light of wavelength λ , the maximum kinetic energy produced is found to be 2 eV. When the same metal is exposed to a wavelength $\frac{\lambda}{5}$ the maximum kinetic energy was found to be 14 eV. Find the value of work function (in eV).

(JEE Arjuna Chemistry M-1)

NUMERICAL TYPE QUESTIONS

29. In a hypothetical H-atom, the mass of electron & its charge is double of what we consider then calculate the magnitude of total energy (in eV) of electron in the 1st orbit of such a hypothetical H-atom?

[Assuming all others concepts and parameter to be same as we considered in Bohr's model.] (Answer upto one decimal)

(JEE Arjuna Chemistry M-1)

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

(Answer upto one decimal)

SUB-ATOMIC PARTICLES AND ATOMIC MODELS

1. Given below are two statements: one is labelled as assertion and the other is labelled as reason.

Assertion (A): Loss of electron from hydrogen atom results in nucleus of $\sim 1.5 \times 10^{-3}$ pm size.

Reason (R): Proton (H^+) always exists in combined form
In the light of the above statements, choose the most appropriate answer from the options given below:

[6 April, 2023 (Shift-I)]

- (a) Both (A) and (R) are correct and (R) is the correct explanation of (A)
- (b) (A) is correct but (R) is not correct
- (c) (A) is not correct but (R) is correct
- (d) Both (A) and (R) are correct but (R) is NOT the correct explanation of (A).

(JEE Arjuna Chemistry M-1)

2. Electrons in a cathode ray tube have been emitted with a velocity of 1000 ms^{-1} . The number of following statements which is/are true about the emitted radiation is _____.

Given : $h = 6 \times 10^{-34} \text{ Js}$, $m_e = 9 \times 10^{-31} \text{ kg}$.

[1 Feb, 2023 (Shift-I)]

- (a) The de-Broglie wavelength of the electron emitted is 666.67 nm
- (b) The characteristic of electrons emitted depend upon the material of the electrodes of the cathode ray tube
- (c) The cathode rays start from cathode and move towards anode
- (d) The nature of the emitted electrons depends on the nature of the gas present in cathode ray tube

(JEE Arjuna Chemistry M-1)

3. Consider an imaginary ion ${}_{22}^{14}\text{X}^{3-}$. The nucleus contains 'a' % more neutrons than the number of electrons in the ion. The value of 'a' is _____. [nearest integer]

[26 July, 2022 (Shift-II)]

(JEE Arjuna Chemistry M-1)

4. If the Thompson model of the atom was correct, then the result of Rutherford's gold foil experiment would have been:

[27 July, 2021 (Shift-II)]

- (a) All α - particles get bounced back by 180°
- (b) α - particles are deflected over a wide range of angles
- (c) All of α - particles pass through the gold foil without decrease in speed
- (d) α - particles pass through the gold foil deflected by small angles and with reduced speed

(JEE Arjuna Chemistry M-1)

5. Amongst the following statements, which was not proposed by Dalton was

[7 Jan, 2020 (Shift-I)]

- (a) Matter consists of invisible atoms
- (b) When gases combine or reproduced in a chemical reaction they do so in a simple ratio by volume provided all gases are at the same temperature & pressure
- (c) Chemical reactions involve reorganisation of atoms. These are neither created nor destroyed in a chemical reaction
- (d) All the atoms of a given element have identical properties including identical mass Atoms of different elements differ in mass

(JEE Arjuna Chemistry M-1)

DEVELOPMENTS LEADING TO THE BOHR'S MODEL OF ATOM

6. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R):

Assertion (A): In the photoelectric effect, the electrons are ejected from the metal surface as soon as the beam of light of frequency greater than threshold frequency strikes the surface.

Reason (R): When the photon of any energy strikes an electron in the atom, transfer of energy from the photon to the electron takes place.

[11 April, 2023 (Shift-I)]

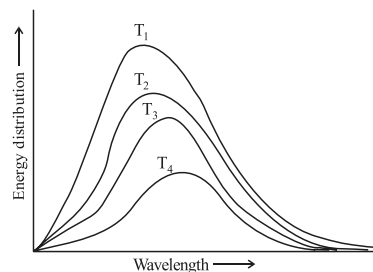
In the light of the above statements, choose the most appropriate answer from the options given below:

- (a) Both (A) and (R) are correct but (R) is NOT the correct explanation of (A)
- (b) (A) is correct but (R) is not correct
- (c) Both (A) and (R) are correct and (R) is the correct explanation of (A)
- (d) (A) is not correct but (R) is correct

(JEE Arjuna Chemistry M-1)

7. Following figure shows spectrum of an ideal black body at four different temperatures. The number of correct statement/s from the following is _____.

[24 Jan, 2023 (Shift-II)]



- (a) $T_4 > T_3 > T_2 > T_1$
- (b) The black body consists of particles performing simple harmonic motion
- (c) The peak of the spectrum shifts to shorter wavelength as temperature increases

(d) $\frac{T_1}{V_1} = \frac{T_2}{V_2} = \frac{T_3}{V_3} \neq \text{constant}$

- (e) The given spectrum could be explained using quantisation of energy

(JEE Arjuna Chemistry M-1)

8. The minimum energy that must be possessed by photons in order to produce the photoelectric effect with platinum metal is:

[Given: The threshold frequency of platinum is $1.3 \times 10^{15} \text{ s}^{-1}$ and $h = 6.6 \times 10^{-34} \text{ J s}$.] [25 June, 2022 (Shift-II)]

- (a) $3.21 \times 10^{-14} \text{ J}$ (b) $6.24 \times 10^{-16} \text{ J}$
(c) $8.58 \times 10^{-19} \text{ J}$ (d) $9.76 \times 10^{-20} \text{ J}$

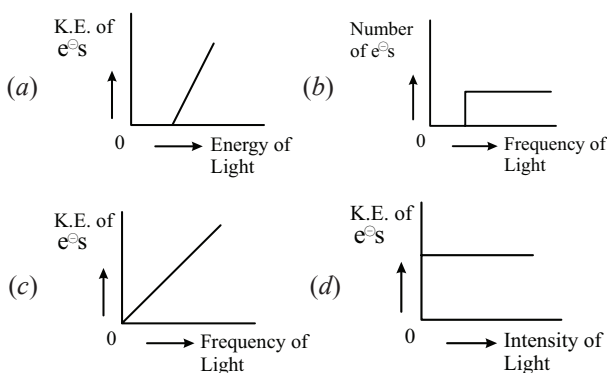
(JEE Arjuna Chemistry M-1)

9. A proton and a Li^{3+} nucleus are accelerated by the same potential. If λ_{Li} and λ_{p} denote the de-Broglie wavelengths of Li^{3+} and proton respectively, then the value of $\frac{\lambda_{\text{Li}}}{\lambda_{\text{p}}}$ is $x \times 10^{-1}$. The value of x is _____ (Rounded off to the nearest integer) [Mass of $\text{Li}^{3+} = 8.3$ times mass of proton]

[24 Feb, 2021 (Shift-I)]

(JEE Arjuna Chemistry M-1)

10. Which of the graphs shown below does not represent the relationship between incident light and the electron ejected from metal surface? [10 Jan, 2019 (Shift-I)]



(JEE Arjuna Chemistry M-1)

11. Consider a Helium (He) atom that absorbs a photon of wavelength 330 nm. The change in the velocity (in cm s^{-1}) of He atom after the photon absorption is _____. (Assume: Momentum is conserved when photon is absorbed).

Use: Planck constant = $6.6 \times 10^{-34} \text{ Js}$, Avogadro number = $6 \times 10^{23} \text{ mol}^{-1}$, molar mass of He = 4 g mol^{-1}

[JEE Adv 2021]

(JEE Arjuna Chemistry M-1)

BOHR'S MODEL FOR HYDROGEN ATOM

12. Given below are two statements:

Statement-I: According to Bohr's model of hydrogen atom, the angular momentum of an electron in a given stationary state is quantised.

Statement-II: The concept of electron in Bohr's orbit, violates the Heisenberg uncertainty principle. In the light of the above statements, choose the most appropriate answer from the options given below: [15 April, 2023 (Shift-I)]

- (a) Both Statement-I and Statement-II are correct
(b) Statement-I is correct but Statement-II is incorrect
(c) Statement-I is incorrect but Statement-II is correct
(d) Both Statement-I and Statement-II are incorrect

(JEE Arjuna Chemistry M-1)

13. If the radius of the 3rd Bohr's orbit of hydrogen atom is r_3 and the radius of 4th Bohr's orbit is r_4 . Then:

[26 June, 2022 (Shift-I)]

- (a) $r_4 = \frac{9}{16} r_3$ (b) $r_4 = \frac{16}{9} r_3$
(c) $r_4 = \frac{3}{4} r_3$ (d) $r_4 = \frac{4}{3} r_3$

(JEE Arjuna Chemistry M-1)

14. The kinetic energy of an electron in the second Bohr orbit of a hydrogen atom is equal to $\frac{h^2}{xma_0^2}$. The value of $10x$ is _____.

(a_0 is radius of Bohr's orbit) (Nearest integer) [Given : $\pi = 3.14$] [27 Aug, 2021 (Shift-I)]

(JEE Arjuna Chemistry M-1)

15. For the Balmer series in the spectrum of H-atom, $\bar{\nu} = R_H \left\{ \frac{1}{n_1^2} - \frac{1}{n_2^2} \right\}$ the correct statements among (I) to (IV) are:

[8 Jan, 2020 (Shift-I)]

- (I) As wavelength decreases, the lines in the series converge
(II) The integer n_1 is equal to n_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

- (a) (II), (III), (IV) (b) (I), (III), (IV)
(c) (I), (II), (III) (d) (I), (II), (IV)

(JEE Arjuna Chemistry M-1)

16. Heat treatment of muscular pain involves radiation of wavelength of about 900 nm. Which spectral line of H-atom is suitable for this purpose?

[$R_H = 1 \times 10^5 \text{ cm}^{-1}$, $h = 6.6 \times 10^{-34} \text{ Js}$, $c = 3 \times 10^8 \text{ ms}^{-1}$]

[11 Jan, 2019 (Shift-I)]

- (a) Paschen, $\infty \rightarrow 3$ (b) Paschen, $5 \rightarrow 3$
(c) Balmer, $\infty \rightarrow 2$ (d) Lyman, $\infty \rightarrow 1$

(JEE Arjuna Chemistry M-1)

17. For He^+ , a transition takes place from the orbit of radius 105.8 pm to the orbit of radius 26.45 pm. The wavelength (in nm) of the emitted photon during the transition is ____.

[Use: Bohr radius, $a = 52.9 \text{ pm}$

Rydberg constant, $R_H = 2.2 \times 10^{-18} \text{ J}$

Planck's constant, $h = 6.6 \times 10^{-34} \text{ J s}$

Speed of light, $c = 3 \times 10^8 \text{ m s}^{-1}$

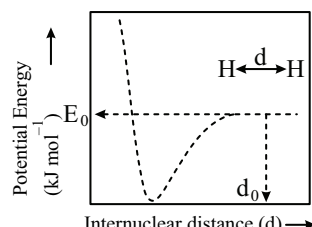
[JEE Adv 2023]

(JEE Arjuna Chemistry M-1)

18. The figure below is the plot of potential energy versus internuclear distance (d) of H_2 molecule in the electronic ground state. What is the value of the net potential energy E_0 (as indicated in the figure) in kJ mol^{-1} , for $d = d_0$ at which the electron-electron repulsion and the nucleus-nucleus repulsion energies are absent? As reference, the potential energy of H atom is taken as zero when its electron and the nucleus are infinitely far apart.

Use Avogadro constant as $6.023 \times 10^{23} \text{ mol}^{-1}$.

[JEE Adv 2020]



(JEE Arjuna Chemistry M-1)

Comprehension (Q. 19 to 20): Answer the following by appropriately matching the lists based on the information given in the paragraph

Consider the Bohr's model of a one-electron atom where the electron moves around the nucleus. In the following Column-I contains some quantities for the n^{th} orbit of the atom and Column-II contains options showing how they depend on n . [JEE Adv 2019]

Column-I		Column-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)	$\propto n^{1/2}$

(JEE Arjuna Chemistry M-1)

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

(a) (II), (R) (b) (I), (P) (c) (I), (T) (d) (II), (Q)

(JEE Arjuna Chemistry M-1)

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

(a) (III), (S) (b) (IV), (Q) (c) (IV), (U) (d) (III), (P)

(JEE Arjuna Chemistry M-1)

TOWARDS QUANTUM MECHANICAL MODEL OF THE ATOM

21. The wave function (Ψ) of 2s is given by

$$\Psi_{2s} = \frac{1}{2\sqrt{2\pi}} \left(\frac{1}{a_0} \right)^{1/2} \left(2 - \frac{r}{a_0} \right) e^{-r/2a_0}$$

At $r = r_0$, radial node is formed. Thus, r_0 in terms of a_0

[30 Jan, 2023 (Shift-II)]

(a) $r_0 = a_0$

(b) $r_0 = 4a_0$

(c) $r_0 = \frac{a_0}{2}$

(d) $r_0 = 2a_0$

(JEE Arjuna Chemistry M-1)

22. The minimum uncertainty in the speed of an electron in an one dimensional region of length $2a_0$ (Where a_0 = Bohr radius 52.9 pm) is _____ km s^{-1} .

(Given: Mass of electron = $9.1 \times 10^{-31} \text{ kg}$, Planck's constant, $h = 6.63 \times 10^{-34} \text{ Js}$)

[29 July, 2022 (Shift-I)]

(JEE Arjuna Chemistry M-1)

23. An accelerated electron has speed of $5 \times 10^6 \text{ ms}^{-1}$ with an uncertainty of 0.02%. The uncertainty in finding its location while in motion is $x \times 10^{-9} \text{ m}$. The value of x is _____. (Nearest integer)

[Use mass of electron = $9.1 \times 10^{-31} \text{ kg}$, $h = 6.63 \times 10^{-34} \text{ Js}$, $\pi = 3.14$]

[25 July, 2021 (Shift-II)]

(JEE Arjuna Chemistry M-1)

24. The de-Broglie wavelength of an electron in the 4th Bohr orbit is:

[9 Jan, 2020 (Shift-I)]

(a) $6\pi a_0$

(b) $4\pi a_0$

(c) $2\pi a_0$

(d) $8\pi a_0$

(JEE Arjuna Chemistry M-1)

25. The de-Broglie wavelength (λ) associated with a photoelectron varies with the frequency (ν) of the incident radiation as [ν_0 is threshold frequency]:

[11 Jan, 2019 (Shift-II)]

(a) $\lambda \propto \frac{1}{(\nu - \nu_0)}$

(b) $\lambda \propto \frac{1}{(\nu - \nu_0)^{1/4}}$

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

(d) $\lambda \propto \frac{1}{(\nu - \nu_0)^{1/2}}$

(JEE Arjuna Chemistry M-1)

QUANTUM MECHANICAL MODEL OF THE ATOM

26. Arrange the following orbitals in decreasing order of energy?

[31 Jan, 2023 (Shift-II)]

(A) $n = 3, l = 0, m = 0$

(B) $n = 4, l = 0, m = 0$

(C) $n = 3, l = 1, m = 0$

(D) $n = 3, l = 2, m = 1$

The correct option for the order is:

(a) $B > D > C > A$

(b) $D > B > C > A$

(c) $A > C > B > D$

(d) $D > B > A > C$

(JEE Arjuna Chemistry M-1)

27. Consider the following statements :

[28 June, 2022 (Shift-II)]

(A) The principal quantum number 'n' is a positive integer

with values of 'n' = 1, 2, 3, ...

- (B) The azimuthal quantum number ' l ' for a given 'n' (principal quantum number) can have values as ' $l = 0, 1, 2, \dots, n$ '
- (C) Magnetic orbital quantum number ' m_l ' for a particular ' l ' (azimuthal quantum number) has $(2l + 1)$ values.
- (D) $\pm 1/2$ are the two possible orientations of electron spin.
- (E) For $l = 5$, there will be a total of 9 orbital

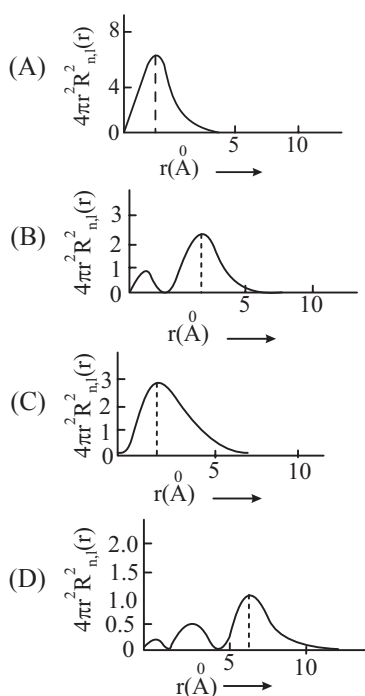
Which of the above statements are correct ?

- (a) (A), (B) and (C) (b) (A), (C), (D) and (E)
- (c) (A), (C) and (D) (d) (A), (B), (C) and (D)

(JEE Arjuna Chemistry M-1)

28. The Plots of radial distribution functions for various orbitals of hydrogen atom against 'r' are given below:

[25 Feb, 2021 (Shift-I)]

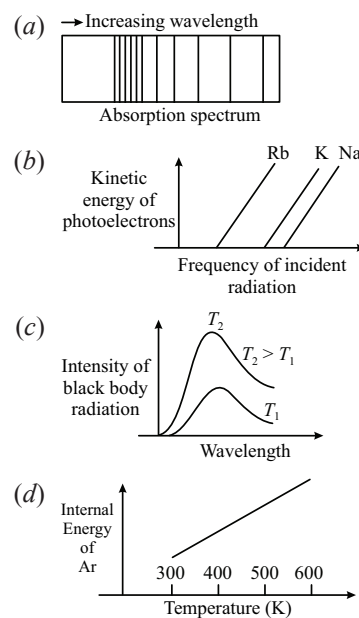


The correct plot for 3s orbital is:

- (a) (D) (b) (B) (c) (A) (d) (C)

(JEE Arjuna Chemistry M-1)

29. The figure that is not a direct manifestation of the quantum nature of atoms is: [2 Sept, 2020 (Shift-I)]



(JEE Arjuna Chemistry M-1)

30. 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 Adv 2019]

- (a) It has 2 angular nodes
- (b) It has 3 radial nodes
- (c) It is a 4d state
- (d) The nuclear charge experienced by the electron in this state is less than $2e$, where e is the magnitude of the electronic charge

(JEE Arjuna Chemistry M-1)

SINGLE CORRECT TYPE QUESTIONS

1. Suppose we have a sample containing 10 identical H-like atoms (hypothetical atoms, Z can be fractional), out of which some are in ground state and some others in a higher energy level n . The total energy of electrons in ground state is -48 eV. When the sample is exposed to radiations of wavelength 310 nm, the electron jump to another higher energy level $(n + 3)$. Upon back-transition, a maximum of 10 different lines are produced. What should be the minimum number of atoms present in energy level n ?

($hc = 12400$ eV Å)

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

(JEE Arjuna Chemistry M-1)

INTEGER TYPE QUESTIONS

2. Mr. Alakh Pandey 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;

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

From the following information given about each alphabet 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 which 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 $k_3 = 1$)

(JEE Arjuna Chemistry M-1)

3. The wave function for the electron in the ground state of H-atom is $\psi_{1s} = (\pi a_0^3)^{-1/2} e^{-r/a_0}$. What is the probability (in terms of 10^{-6}) of finding an electron somewhere inside a small sphere of radius 10^{-12} m centred on nucleus?

(JEE Arjuna Chemistry M-1)

4. For $3s$ orbital of hydrogen atom, the normalised wave function is

$$\psi_{3s} = \frac{1}{81\sqrt{3}\pi} \left(\frac{1}{a_0} \right)^{3/2} \left[27 - \frac{18r}{a_0} + \frac{2r^2}{a_0^2} \right] e^{-\frac{r}{3a_0}}$$

If distance between the radial nodes is d , calculate the value of $\frac{d}{1.73a_0}$.

(JEE Arjuna Chemistry M-1)

NUMERICAL TYPE QUESTIONS

5. The normalized wave function for the ground state of

hydrogen atom is $\psi_{1s} = \left(\frac{1}{\pi a_0^3} \right)^{1/2} e^{-\frac{r}{a_0}}$ where a_0 is the first

Bohr radius. Calculate the probability of finding the electron somewhere between 0 and $2a_0$.

(Answer upto three decimal)

(JEE Arjuna Chemistry M-1)

6. The de-Broglie wavelength of electron of He^+ ion is 3.329Å . If the photon emitted upon de-excitation of this He^+ ion is made to hit H-atom in its ground state so as to liberate electron from it, what will be the de-Broglie's wavelength (in Å) of photoelectron?

(Answer upto three decimal)

(JEE Arjuna Chemistry M-1)

PASSAGE-I

Let us assume a different atomic model in which electron revolves around the nucleus (proton) at a separation r under the action of force which is different from electrostatic force of attraction. The potential energy between an electron and the proton due to this force is given by $U = -klr^4$, where k is a constant. This hypothetical atom is obeying Bohr's quantization condition.

7. The radius of n th Bohr's orbit is

- (a) $r = \frac{\pi}{nh} \sqrt{km}$ (b) $r = \frac{2\pi}{nh} \sqrt{km}$
(c) $r = \frac{4\pi}{nh} \sqrt{km}$ (d) $r = \frac{8\pi}{nh} \sqrt{km}$

(JEE Arjuna Chemistry M-1)

8. The speed of electron in the n^{th} orbit is

$$\begin{array}{ll} (a) \quad V = \frac{nh}{8\pi^2 m \sqrt{km}} & (b) \quad V = \frac{n^2 h}{8\pi^2 m \sqrt{km}} \\ (c) \quad V = \frac{nh^2}{4\pi^2 m \sqrt{km}} & (d) \quad V = \frac{n^2 h^2}{8\pi^2 m \sqrt{km}} \end{array}$$

(JEE Arjuna Chemistry M-1)

9. The total energy of the electron in the n^{th} orbit is

$$\begin{array}{ll} (a) \quad \text{T.E.} = \frac{-n^4 h^4}{128\pi^4 m^2 k} & (b) \quad \text{T.E.} = \frac{n^4 h^4}{128\pi^4 m^2 k} \\ (c) \quad \text{T.E.} = \frac{n^4 h^4}{256\pi^4 m^2} & (d) \quad \text{T.E.} = \frac{-n^4 h^4}{256\pi^4 m^2} \end{array}$$

(JEE Arjuna Chemistry M-1)

PASSAGE-II

The wave function for an atomic orbital of single electron atom or ion is

$$\Psi(r, \theta, \phi) = \frac{2}{3} \left(\frac{Z}{3a_0} \right)^{3/2} (1 - \sigma)(12 - 8\sigma + \sigma^2) \cdot \sigma \cdot e^{-\sigma/2} \cdot \cos\theta$$

where $\sigma = \frac{2Zr}{na_0}$ and $a_0 = 0.529 \text{ \AA}$. All other parameters have their usual meaning

10. The number of radial and angular nodes for the orbital is, respectively.

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

(JEE Arjuna Chemistry M-1)

11. The atomic orbital should be

- (a) 4p (b) 5p
(c) 5d (d) 5f

(JEE Arjuna Chemistry M-1)

12. If θ is the angle measured from Z-axis, then the orbital should be

- (a) p_x (b) p_y
(c) p_z (d) d_{z^2}

(JEE Arjuna Chemistry M-1)

13. The maximum distance of radial node from the nucleus is

$$\begin{array}{ll} (a) \quad \frac{a_0}{Z} & (b) \quad \frac{3a_0}{Z} \\ (c) \quad \frac{6a_0}{Z} & (d) \quad \frac{15a_0}{Z} \end{array}$$

(JEE Arjuna Chemistry M-1)

PASSAGE-III

Consider a system containing a negatively charged pion (π^- , $m_\pi = 273 m_e$) orbiting around a stationary nucleus of atomic number Z . The total energy (E_n) of ion is half of its potential energy (PE_n) in n^{th} stationary state. The motion of the pion can be assumed to be in a uniform circular motion with centripetal force given by the force of attraction between the positive nucleus and the pion. Assume that pion revolves only in the stationary states defined by the quantisation of its angular momentum about the nucleus as per Bohr's model.

14. The potential energy (PE_n) of ion follows:

$$\begin{array}{ll} (a) \quad PE_n \propto m_\pi \left(\frac{n^2}{Z} \right) & (b) \quad PE \propto m_\pi \left(\frac{Z^2}{n^2} \right) \\ (c) \quad PE_n \propto \frac{1}{m_\pi} \left(\frac{n^2}{Z^2} \right) & (d) \quad PE_n \propto \frac{1}{m_\pi} \left(\frac{Z^2}{n^2} \right) \end{array}$$

(JEE Arjuna Chemistry M-1)

15. Number of waves made by the pion when orbiting in third excitation state are:

- (a) 3 (b) 4 (c) $3Z^2$ (d) $4Z^2$

(JEE Arjuna Chemistry M-1)

16. The longest wavelength radiation emitted in the emission spectrum when the pion de-excites from $n = 3$ to ground state lies in which of the following region?

- (a) UV (b) Visible
(c) Infra-Red (d) Cannot be calculated

(JEE Arjuna Chemistry M-1)

17. The wavelength (λ_n) of the pion orbiting in n^{th} stationary state is given by

$$\begin{array}{ll} (a) \quad \lambda_\pi \propto \frac{n}{m_\pi Z} & (b) \quad \lambda_\pi \propto \frac{m_\pi n}{Z} \\ (c) \quad \lambda_\pi \propto \frac{m_\pi Z}{n} & (d) \quad \lambda_\pi \propto \frac{Z}{m_\pi n} \end{array}$$

(JEE Arjuna Chemistry M-1)

Answer Key



CONCEPT APPLICATION

- | | | | | | | | | | |
|---------|---------|---------------|---------|---------|---------|---------|---------|---------|---------|
| 1. (a) | 2. (b) | 3. (c) | 4. (b) | 5. (a) | 6. (d) | 7. (b) | 8. (c) | 9. (a) | 10. (b) |
| 11. (a) | 12. (a) | 13. (c) | 14. (b) | 15. (b) | 16. (a) | 17. (d) | 18. (c) | 19. (d) | 20. (c) |
| 21. (b) | 22. (b) | 23. (0.423 Å) | | 24. (c) | 25. (a) | 26. (d) | 27. (a) | 28. (b) | 29. (b) |
| 30. (a) | 31. (c) | 32. (d) | 33. (a) | | | | | | |

SCHOOL LEVEL PROBLEMS

- | | | | | | | | | | |
|---------|---------|--|--------|--------|--------|--------|--------|--------|---------|
| 1. (a) | 2. (d) | 3. (b) | 4. (a) | 5. (d) | 6. (b) | 7. (c) | 8. (d) | 9. (c) | 10. (a) |
| 11. (d) | 12. (a) | 24. (i)-(d), (ii)-(a), (iii)-(c), (iv)-(c) | | | | | | | |

PRARAMBH (TOPICWISE)

- | | | | | | | | | | |
|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 1. (a) | 2. (c) | 3. (b) | 4. (d) | 5. (c) | 6. (d) | 7. (c) | 8. (b) | 9. (a) | 10. (d) |
| 11. (d) | 12. (c) | 13. (a) | 14. (a) | 15. (d) | 16. (c) | 17. (c) | 18. (c) | 19. (d) | 20. (c) |
| 21. (a) | 22. (b) | 23. (a) | 24. (a) | 25. (b) | 26. (a) | 27. (b) | 28. (b) | 29. (c) | 30. (b) |
| 31. (c) | 32. (a) | 33. (d) | 34. (c) | 35. (c) | 36. (c) | 37. (b) | 38. (c) | 39. (d) | 40. (d) |
| 41. (c) | 42. (c) | 43. (c) | 44. (a) | 45. (b) | 46. (c) | 47. (d) | 48. (d) | 49. (a) | 50. (b) |
| 51. (c) | 52. (d) | 53. (a) | 54. (d) | 55. (b) | 56. (b) | 57. (a) | 58. (b) | 59. (b) | 60. (b) |
| 61. (d) | 62. (c) | 63. (a) | 64. (c) | 65. (c) | 66. (c) | 67. (b) | 68. (d) | 69. (d) | 70. (b) |

PRABAL (JEE MAIN LEVEL)

- | | | | | | | | | | |
|------------|----------|----------|---------|----------|----------|---------|----------|---------|----------|
| 1. (a) | 2. (c) | 3. (d) | 4. (c) | 5. (a) | 6. (a) | 7. (b) | 8. (b) | 9. (d) | 10. (c) |
| 11. (b) | 12. (d) | 13. (c) | 14. (a) | 15. (c) | 16. (d) | 17. (b) | 18. (b) | 19. (c) | 20. (d) |
| 21. (b) | 22. (d) | 23. (c) | 24. (d) | 25. (c) | 26. (c) | 27. (c) | 28. (b) | 29. (d) | 30. (b) |
| 31. (d) | 32. (b) | 33. (c) | 34. (b) | 35. (c) | 36. [6] | 37. [6] | 38. [26] | 39. [4] | 40. [4] |
| 41. [1240] | 42. [31] | 43. [12] | 44. [5] | 45. [90] | 46. [97] | 47. [1] | 48. [4] | 49. [3] | 50. [17] |

PARIKSHIT (JEE ADVANCED LEVEL)

- | | | | | | | | | | |
|-------------|-------------|-----------|-----------|-------------|-------------|---------|------------|-------------|---------------|
| 1. (b) | 2. (d) | 3. (c) | 4. (c) | 5. (a) | 6. (a) | 7. (c) | 8. (a,b,c) | 9. (a,b,c) | 10. (a,b,c,d) |
| 11. (a,b,c) | 12. (a,b,c) | 13. (a,c) | 14. (b,c) | 15. (a,b,c) | 16. (a,b,c) | 17. (a) | 18. (b) | 19. (c) | 20. (d) |
| 21. (c) | 22. (b) | 23. [14] | 24. [5] | 25. [3] | 26. [5] | 27. [9] | 28. [1] | 29. [435.2] | 30. [1740.6] |

PYQ's (PAST YEAR QUESTIONS)

- | | | | | | | | | | |
|-----------|---------|-----------|------------|---------|---------|----------|----------------|---------|---------|
| 1. (d) | 2. [2] | 3. [4] | 4. (d) | 5. (b) | 6. (b) | 7. [2] | 8. (c) | 9. [2] | 10. (c) |
| 11. [30] | 12. (a) | 13. (b) | 14. [3155] | 15. (c) | 16. (a) | 17. [30] | 18. [-5246.49] | | 19. (c) |
| 20. (d) | 21. (d) | 22. [548] | 23. [58] | 24. (d) | 25. (d) | 26. (b) | 27. (c) | 28. (a) | 29. (c) |
| 30. (a,c) | | | | | | | | | |

PW CHALLENGERS

- | | | | | | | | | | |
|---------|-------------|--------|---------|------------|------------|---------|---------|--------|---------|
| 1. (a) | 2. [300303] | 3. [9] | 4. [3] | 5. [0.762] | 6. [2.351] | 7. (c) | 8. (d) | 9. (c) | 10. (a) |
| 11. (b) | 12. (c) | | 13. (d) | 14. (b) | 15. (b) | 16. (d) | 17. (a) | | |