MODERN PHYSICS-1

KEY CONCEPT

PHOTO ELECTRIC EFFECT

PHOTOELECTRIC EFFECT

It was discovered by Hertz in 1887. He found that when the negative plate of an electric discharge tube was illuminated with ultraviolet light, the electric discharge took place more readily. Further experiments carried out by Hallwachs confirmed that certain negatively charged particles are emitted, when a Zn plate is illuminated with ultraviolet light. These particles were identified as electrons.

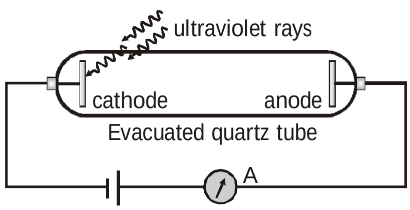
The phenomenon of emission of electrons from the surface of certain substances, when suitable radiations of certain frequency or wavelength are incident upon it is called photoelectric effect.

EXPLANATION OF PHOTOELECTRIC EFFECT

- **On the basis of wave theory** :According to wave theory, light is an electromagnetic radiation consisting of oscillating electric field vectors and magnetic field vectors. When electromagnetic radiations are incident on a metal surface, the free electrons [free electrons means the electrons which are loosely bound and free to move inside the metal] absorb energy from the radiation. This occurs by the oscillations of electron under the action of electric field vector of electromagnetic radiation. When an electron acquires sufficiently high energy so that it can overcome its binding energy, it comes out from the metal.
- **On the basis of photon theory:** According to photon theory of light, light consists of particles (called photons). Each particle carries a certain amount of energy with it. This energy is given by $E=h\nu$, where h is the Plank's constant and ν is the frequency. When the photons are incident on a metal surface, they collide with electrons. In some of the collisions, a photon is absorbed by an electron. Thus an electron gets energy $h\nu$. If this energy is greater than the binding energy of the electron, it comes out of the metal surface. The extra energy given to the electron becomes its kinetic energy.

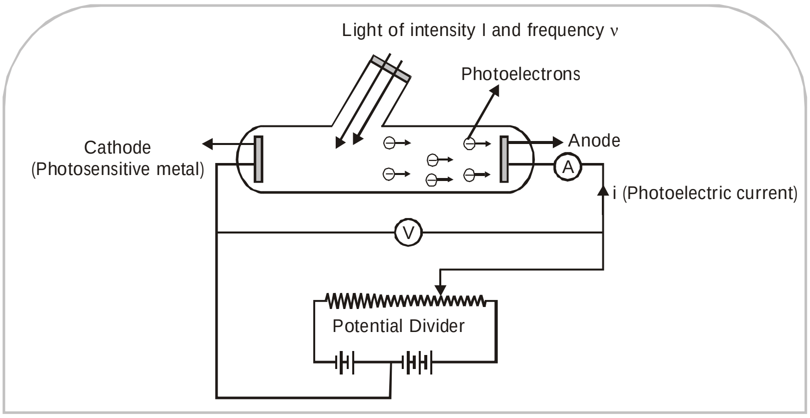
EXPERIMENTS

- **Hertz Experiment**
  Hertz observed that when ultraviolet rays are incident on negative plate of electric discharge tube then conduction takes place easily in the tube.



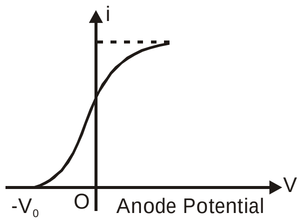
- **Hallwach experiment :** Hallwach observed that if negatively charged Zn plate is illuminated by U.V. light, its negative charge decreases and it becomes neutral and after some time it gains positive charge. It means in the effect of light, some negative charged particles are emitted from the metal.
- **Lenard Explanation :** He told that when ultraviolet rays are incident on cathode, electrons are ejected. These electrons are attracted by anode and circuit is completed due to flow of electrons and current flows. When U.V. rays incident on anode, electrons are ejected but current does not flow.
  For the photo electric effect the light of short wavelength (or high frequency) is more effective than the light of long wavelength (or low frequency)

- **Experimental study of photoelectric Effect :** When light of frequency ν and intensity I falls on the cathode, electrons are emitted from it. The electrons are collected by the anode and a current flows in the circuit. This current is called photoelectric current. This experiment is used to study the variation of photoelectric current with different factors like intensity, frequency and the potential difference between the anode and cathode.



(i) Variation of photoelectric current with potential difference

With the help of the above experimental setup, a graph is obtained between current and potential difference. The potential difference is varied with the help of a potential divider. The graph obtained is shown below.



The main points of observation are :

(a) At zero anode potential, a current exists. It means that electrons are emitted from cathode with some kinetic energy.

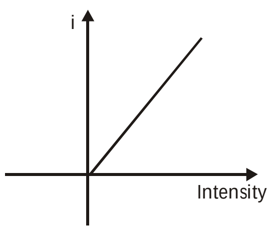
(b) As anode potential is increased, current increases. This implies that different electrons are emitted with different kinetic energies.

(c) After a certain anode potential, current acquires a constant value called saturation current. Current acquires a saturation value because the number of electrons emitted7 per second from the cathode are fixed.

(d) At a certain negative potential, the photoelectric current becomes zero. This is called stopping potential (V_0). Stopping potential is a measure of maximum kinetic energy of the emitted electrons. Let KE_{max} be the maximum kinetic energy of an emitted electron, then $KE_{max} = eV_0$.

(ii) Variation of current with intensity

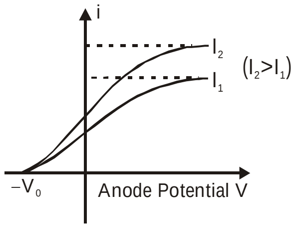
The photoelectric current is found to be directly proportional to intensity of incident radiation.



(iii) Effect of intensity on saturation current and stopping potential

(a) Saturation current increases with increase in intensity.

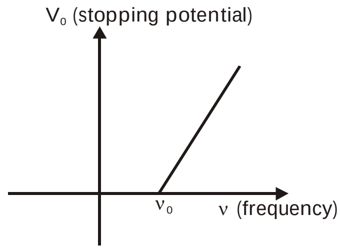
(b) Stopping potential (and therefore maximum kinetic energy) is independent of intensity.



(iv) Effect of frequency

(a) Stopping potential is found to vary with frequency of incident light linearly. Greater the frequency of incident light, greater the stopping potential.

(b) There exists a certain minimum frequency ν_0 below which no stopping potential is required as no emission of electrons takes place. This frequency is called threshold frequency. For photoelectric emission to take place, $\nu > \nu_0$.



IMPORTANT POINTS

- Photo electric effect is an instantaneous process, as soon as light is incident on the metal, photo electrons are emitted.
- Stopping potential does not depend on the distance between cathode and anode.
- The work function represented the energy needed to remove the least tightly bounded electrons from the surface. It depends only on nature of the metal and independent of any other factors.

- **Failure of wave theory of light**

(i) According to wave theory when light incident on a surface, energy is distributed continuously over the surface. So that electron has to wait to gain sufficient energy to come out. But in experiment there is no time lag. Emission of electrons takes place in less than 10^{-9} s. This means, electron does not absorb energy. They get all the energy once.

(ii) When intensity is increased, more energetic electrons should be emitted. So that stopping potential should be intensity dependent. But it is not observed.

(iii) According to wave theory, if intensity is sufficient then, at each frequency, electron emission is possible. It means there should not be existence of threshold frequency.

- **Einstein's Explanation of Photoelectric Effect**

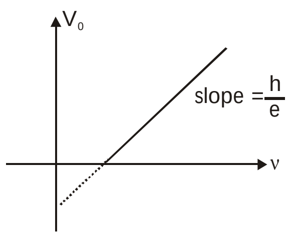
Einstein explained photoelectric effect on the basis of photon–electron interaction. The energy transfer takes place due to collisions between an electrons and a photon. The electrons within the target material are held there by electric force. The electron needs a certain minimum energy to escape from this pull. This minimum energy is the property of target material and it is called the work function. When a photon of energy E=hν collides with and transfers its energy to an electron, and this energy is greater than the work function, the electron can escape through the surface.

- **Einstein's Photoelectric Equation** $h\nu = \phi + KE_{max}$

Here hν is the energy transferred to the electron. Out of this, ϕ is the energy needed to escape.

The remaining energy appears as kinetic energy of the electron.

Now $KE_{max} = eV_0$ (where V_0 is stopping potential)



$$\therefore\ h\nu = \phi + eV_0 \Rightarrow V_0 = \left(\frac{h}{e}\right)\nu - \frac{\phi}{e}$$

Thus, the stopping potential varies linearly with the frequency of incident radiation.

Slope of the graph obtained is $\frac{h}{e}$. This graph helps in determination of Planck's constant.

IMPORTANT POINTS

- Einstein's Photo Electric equation is based on conservation of energy.
- Einstein explained P.E.E. on the basis of quantum theory, for which he was awarded noble prize.
- According to Einstein one photon can eject one e^- only. But here the energy of incident photon should greater or equal to work function.
- In photoelectric effect all photoelectrons do not have same kinetic energy. Their KE range from zero toE_{max} which depends on frequency of incident radiation and nature of cathode.
- The photo electric effect takes place only when photons strike bound electrons because for free electrons energy and momentum conservations do not hold together.

Ex. Calculate the possible velocity of a photoelectron if the work function of the target material is 1.24 eV and wavelength of light is 4.36×10^{-7} m. What retarding potential is necessary to stop the emission of electrons?

Sol. As $KE_{max} = h\nu - \phi \Rightarrow \frac{1}{2}mv_{max}^2 = h\nu - \phi = \frac{hc}{\lambda} - \phi$

$$v_{max} = \sqrt{\frac{2\left(\frac{hc}{\lambda} - \phi\right)}{m}} = \sqrt{\frac{2\left(\frac{6.63\times10^{-34}\times3\times10^{8}}{4.36\times10^{-7}} - 1.24\times1.6\times10^{-19}\right)}{9.11\times10^{-31}}} = 7.523 \times 10^5 \text{ m/s}$$

$\therefore$ The speed of a photoelectron can be any value between 0 and 7.43×10^5 m/s

If V_0 is the stopping potential, then $eV_0 = \frac{1}{2}mv_{max}^2$

$$\Rightarrow V_0 = \frac{1}{2}\frac{mv_{max}^2}{e} = \frac{hc}{e\lambda} - \frac{\phi}{e} = \frac{12400}{4360} - 1.24 = 1.60 \text{ V} \quad \left[\because \frac{hc}{e} = 12400 \times 10^{-10}\, \text{V} - \text{m}\right]$$

Ex. The surface of a metal of work function ϕ is illuminated by light whose electric field component varies with time as $E = E_0 [1 + \cos\omega t] \sin\omega_0 t$. Find the maximum kinetic energy of photoelectrons emitted from the surface.

Sol. The given electric field component is $E=E_0 \sin\omega_0 t + E_0 \sin\omega_0 t \cos\omega t = E_0 \sin\omega_0 t + \frac{E_0}{2}[\sin(\omega_0 + \omega)t + \sin(\omega_0 - \omega)t]$

$\therefore$ The given light comprises three different frequencies viz. ω, $\omega_0 + \omega$, $\omega_0 - \omega$

The maximum kinetic energy will be due to most energetic photon.

$$\therefore KE_{max} = h\nu - \phi = \frac{h(\omega + \omega_0)}{2\pi} - \phi \qquad \left(\because \omega = 2\pi\nu \text{ or } \nu = \frac{\omega}{2\pi}\right)$$

Ex. When light of wavelength λ is incident on a metal surface, stopping potential is found to be x. When light of wavelength $n\lambda$ is incident on the same metal surface, stopping potential is found to be $\frac{x}{n+1}$. Find the threshold wavelength of the metal.

Sol. Let λ_0 is the threshold wavelength. The work function is $\phi = \frac{hc}{\lambda_0}$.

Now, by photoelectric equation ex = $\frac{hc}{\lambda} - \frac{hc}{\lambda_0}$ ...(i) $\frac{ex}{n+1} = \frac{hc}{n\lambda} - \frac{hc}{\lambda_0}$ ...(ii)

From (i) and (ii) $\frac{hc}{\lambda} - \frac{hc}{\lambda_0} = (n+1)\frac{hc}{n\lambda} - (n+1)\frac{hc}{\lambda_0} \Rightarrow \frac{nhc}{\lambda_0} = \frac{hc}{n\lambda} \Rightarrow \lambda_0 = n^2\lambda$

PHOTON THEORY OF LIGHT

- A photon is a particle of light moving with speed 299792458 m/s in vacuum.
- The speed of a photon is independent of frame of reference. This is the basic postulate of theory of relativity.
- The rest mass of a photon is zero. i.e. photons do not exist at rest.
- Effective mass of photon $m = \frac{E}{c^2} = \frac{hc}{c^2\lambda} = \frac{h}{c\lambda}$ i.e. $m \propto \frac{1}{\lambda}$

  So mass of violet light photon is greater than the mass of red light photon. ($\because \lambda_R > \lambda_V$)
- According to Planck the energy of a photon is directly proportional to the frequency of the radiation.

  $E \propto \nu$ or $E = h\nu$

  $E = \frac{hc}{\lambda}$ joule ($\because c = \nu\lambda$) or $E = \frac{hc}{\lambda e} = \frac{12400}{\lambda}$ eV – Å

  $\left[\because \frac{hc}{e} = 12400(\mathring{A} - eV)\right]$

  Here E = energy of photon, c = speed of light, h = Planck's constant, e = charge of electron
  h = 6.62 × 10^{-34} J–s, ν = frequency of photon, λ = wavelength of photon
- Linear momentum of photon $p = \frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$
- A photon can collide with material particles like electron. During these collisions, the total energy and total momentum remain constant.
- Energy of light passing through per unit area per unit time is known as intensity of light.

  Intensity of light $I = \frac{E}{At} = \frac{P}{A}$ ...(i)

  Here P = power of source, A = Area, t = time taken
  E = energy incident in t time = $Nh\nu$, N = number of photon incident in t time

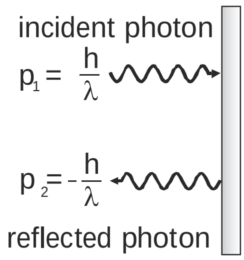
  Intensity $I = \frac{N(h\nu)}{At} = \frac{n(h\nu)}{A}$ ...(ii)

  $\left[\because n = \frac{N}{t} = \text{no. of photon per sec.}\right]$

  From equation (i) and (ii), $\frac{P}{A} = \frac{n(h\nu)}{A} \Rightarrow n = \frac{P}{h\nu} = \frac{P\lambda}{hc} = 5 \times 10^{24} J^{-1} m^{-1} \times P \times \lambda$

- When photons fall on a surface, they exert a force and pressure on the surface. This pressure is called radiation pressure.
- **Force exerted on perfectly reflecting surface**

  Let 'N' photons are there in time t,



Momentum before striking the surface $(p_1) = \frac{Nh}{\lambda}$

Momentum after striking the surface $(p_2) = -\frac{Nh}{\lambda}$

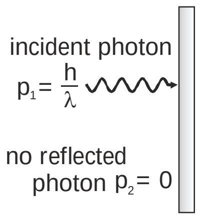
Change in momentum of photons $= p_2 - p_1 = \frac{-2Nh}{\lambda}$

But change in momentum of surface $= \Delta p = \frac{2Nh}{\lambda}$

So that force on surface $F = \frac{2Nh}{t\lambda} = n\left[\frac{2h}{\lambda}\right]$ but $n = \frac{P\lambda}{hc}$

$\therefore F = \frac{2h}{\lambda} \times \frac{P\lambda}{hc} = \frac{2P}{c}$ and Pressure $= \frac{F}{A} = \frac{2P}{cA} = \frac{2I}{c}$ $\left[\because I = \frac{P}{A}\right]$

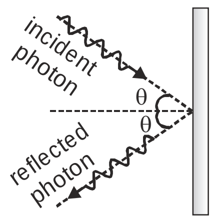
- **Force exerted on perfectly absorbing surface**



$F = \frac{p_1 - p_2}{t} = \frac{\frac{Nh}{\lambda} - 0}{t} = \frac{Nh}{t\lambda} = n\frac{h}{\lambda}$

$F = \frac{P}{c}$ $\left(\because n = \frac{P\lambda}{hc}\right)$ and Pressure $= \frac{F}{A} = \frac{P}{Ac} = \frac{I}{c}$

- **When a beam of light is incident at angle θ on perfectly reflector surface**



$F = \frac{2P}{c}\cos\theta = n\left[\frac{2h}{\lambda}\right]\cos\theta = \frac{2IA\cos\theta}{c}$

Pressure $= \frac{F}{A} = \frac{2I\cos^2\theta}{c}$

Ex. The intensity of sunlight on the surface of earth is 1400 W/m^2. Assuming the mean wavelength of sunlight to be 6000 Å, calculate:–

(a) The photon flux arriving at 1 m^2 area on earth perpendicular to light radiations and

(b) The number of photons emitted from the sun per second (Assuming the average radius of Earth's orbit to be 1.49×10^{11} m)

Sol. (a) Energy of a photon $E = \frac{hc}{\lambda} = \frac{12400}{6000} = 2.06 \text{ eV} = 3.3 \times 10^{-19}$ J

Photon flux $= \frac{IA}{E} = \frac{1400 \times 1}{3.3 \times 10^{-19}} = 4.22 \times 10^{21}$ photons/sec.

(b) Number of photons emitted per second $n = \frac{P}{E} = \frac{IA}{E} = \frac{1400 \times 4\pi \times (1.49 \times 10^{11})^2}{3.3 \times 10^{-19}} = 1.18 \times 10^{45}$

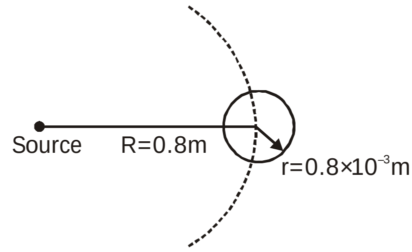
Ex. In a photoelectric setup, a point source of light of power 3.2×10^{-3} W emits monochromatic photons of energy 5.0 eV. The source is located at a distance 0.8 m from the centre of a stationary metallic sphere of work function 3.0 eV and radius 8×10^{-3} m. The efficiency of photoelectron emission is one for every 10^6 incident photons. Assuming that the sphere is isolated and initially neutral and that photoelectrons are instantly swept away after emission, Find (i) the number of photoelectrons emitted per second. (ii) the time t after light source is switched on, at which photoelectron emission stops.

Sol. Energy of a single photon E=5.0 eV = 8×10^{-19} J

Power of source P = 3.2×10^{-3} W

$\therefore$ number of photons emitted per second $n = \frac{P}{E} = \frac{3.2 \times 10^{-3}}{8 \times 10^{-19}} = 4 \times 10^{15}$/s

The number of photons incident per second on metal surface is $n_0 = \frac{n}{4\pi R^2} \times \pi r^2$



$$n_0 = \frac{4 \times 10^{15}}{4\pi(0.8)^2} \times \pi\left(8 \times 10^{-3}\right)^2 = 1.0 \times 10^{11} \text{ photon/s}$$

Number of electrons emitted = $\frac{1.0 \times 10^{11}}{10^6} = 10^5$ /s

$$KE_{max} = h\nu - \phi = 5.0 - 3.0 = 2.0 \text{ eV}$$

The photoelectron emission stops, when the metallic sphere acquires stopping potential.

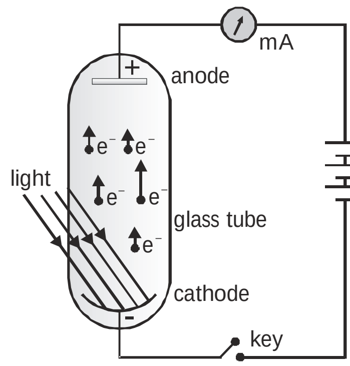
As KE_{max} = 2.0 eV $\Rightarrow$ Stopping potential $V_0 = 2V \Rightarrow 2 = \frac{q}{4\pi\varepsilon_0 r} \Rightarrow q = 1.78 \times 10^{-12}$ C

Now charge q = (number of electrons/second) × t× e $\Rightarrow t = \frac{1.78 \times 10^{-12}}{10^5 \times 1.6 \times 10^{-19}} = 111$s

PHOTO CELL

A photo cell is a practical application of the phenomenon of photo electric effect, with the help of photo cell light energy is converted into electrical energy.

- **Construction :** A photo cell consists of an evacuated sealed glass tube containing anode and a concave cathode of suitable emitting material such as Cesium (Cs).
- **Working:** When light of frequency greater than the threshold frequency of cathode material falls on the cathode, photoelectrons emitted are collected by the anode and an electric current starts flowing in the external circuit. The current increase with the increase in the intensity of light. The current would stop, if the light does not fall on the cathode.



- **Application**

(i) In television camera.

(ii) In automatic door

(iii) Burglar's alarm

(iv) Automatic switching of street light and traffic signals.

MATTER WAVES THEORY

DUAL NATURE OF LIGHT

Experimental phenomena of light reflection, refraction, interference, diffraction are explained only on the basis of wave theory of light. These phenomena verify the wave nature of light. Experimental phenomena of light photoelectric effect and Crompton effect, pair production and positron inhalational can be explained only on the basis of the particle nature of light. These phenomena verify the particle nature of light.

It is inferred that light does not have any definite nature, rather its nature depends on its experimental phenomenon. This is known as the dual nature of light. The wave nature and particle nature both can not be possible simultaneously.

De-Broglie HYPOTHESIS

De Broglie imagined that as light possess both wave and particle nature, similarly matter must also posses both nature, particle as well as wave. De Broglie imagined that despite particle nature of matter, waves must also be associated with material particles. Wave associated with material particles, are defined as matter waves.

- **De Broglie wavelength associated with moving particles**

If a particle of mass m moving with velocity v

Kinetic energy of the particle $E=\frac{1}{2}mv^2=\frac{p^2}{2m}$ momentum of particle p = mv = $\sqrt{2mE}$ the wave length associated with the particles is $\lambda=\frac{h}{p}=\frac{h}{mv}=\frac{h}{\sqrt{2mE}}$ $\lambda\propto\frac{1}{p}\Rightarrow\lambda\propto\frac{1}{v}\Rightarrow\lambda\propto\frac{1}{\sqrt{E}}$

The order of magnitude of wave lengths associated with macroscopic particles is 10^{-24} Å.

The smallest wavelength whose measurement is possible is that of γ – rays ($\lambda\simeq10^{-5}$ Å). This is the reason why the wave nature of macroscopic particles is not observable.

The wavelength of matter waves associated with the microscopic particles like electron, proton, neutron, α – particle, atom, molecule etc. is of the order of 10^{-10} m, it is equal to the wavelength of X–rays, which is within the limit of measurement. Hence the wave nature of these particles is observable.

- **De Broglie wavelength associated with the charged particles**

Let a charged particle having charge q is accelerated by potential difference V.

Kinetic energy of this particle $E=\frac{1}{2}mv^2=qV$ Momentum of particle $p=mv=\sqrt{2mE}=\sqrt{2mqV}$

The De Broglie wavelength associated with charged particle $\lambda=\frac{h}{p}=\frac{h}{\sqrt{2mE}}=\frac{h}{\sqrt{2mqV}}$

- **For an Electron** $m_e = 9.1\times10^{-31}$ kg, $q = 1.6\times10^{-19}$ C, $h = 6.62\times10^{-34}$ J–s

De Broglie wavelength associated with electron $\lambda=\frac{6.62\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}V}}$

$$\lambda=\frac{12.27\times10^{-10}}{\sqrt{V}}\text{ meter }=\frac{12.27}{\sqrt{V}}\text{ Å} \quad \text{so } \lambda\propto\frac{1}{\sqrt{V}}$$

Potential difference required to stop an electron of wavelength λ is $V = \frac{150.6}{\lambda^2}$ volt $(Å)^2$

- **For Proton** $m_p = 1.67 \times 10^{-27}$ kg
  De Broglie wavelength associated with proton

$$\lambda_p = \frac{6.62\times10^{-34}}{\sqrt{2\times1.67\times10^{-27}\times1.6\times10^{-19}V}}\ ;\ \lambda_p = \frac{0.286\times10^{-10}}{\sqrt{V}}\text{ meter } = \frac{0.286}{\sqrt{V}}\ Å$$

- **For Deuteron** $m_d = 2 \times 1.67 \times 10^{-27}$ kg, $q_d = 1.6 \times 10^{-19}$ C

$$\lambda_d = \frac{6.62\times10^{-34}}{\sqrt{2\times2\times1.67\times10^{-27}\times1.6\times10^{-19}V}} = \frac{0.202}{\sqrt{V}}\ Å$$

- **For α Particles** $q_\alpha = 2 \times 1.6 \times 10^{-19}$ C, $m_\alpha = 4 \times 1.67 \times 10^{-27}$ kg

$$\therefore \lambda_\alpha = \frac{6.62\times10^{-34}}{\sqrt{2\times4\times1.67\times10^{-27}\times2\times1.6\times10^{-19}V}} = \frac{0.101}{\sqrt{V}}\ Å$$

DE BROGLIE WAVELENGTH ASSOCIATED WITH UNCHARGED PARTICLES

- **Kinetic energy of uncharged particle** $E = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

  m = mass of particle, v = velocity of particle, p = momentum of particle.

- **Velocity of uncharged particle** $v = \sqrt{\frac{2E}{m}}$

- **Momentum of particle** $p = mv = \sqrt{2mE}$

  wavelength associated with the particle $\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$

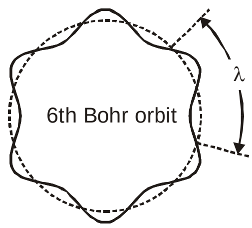
  Kinetic energy of the particle in terms of its wavelength $E = \frac{h^2}{2m\lambda^2} = \frac{h^2}{2m\lambda^2\times1.6\times10^{-19}}$ eV

  For a neutron $m_n = 1.67 \times 10^{-27}$ kg

$$\therefore\ \lambda = \frac{6.62\times10^{-34}}{\sqrt{2\times1.67\times10^{-27}\times E}} = \frac{0.286\times10^{-10}}{\sqrt{E}}\text{meter}\sqrt{eV} = \frac{0.286}{\sqrt{E}}\ Å\sqrt{eV}$$

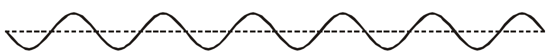
EXPLANATION OF BOHR QUANTIZATION CONDITION

According to De Broglie electron revolves round the nucleus in the form of stationary waves (i. e. wave packet) in the similar fashion as stationary waves in a vibrating string. Electron can stay in those circular orbits whose circumference is an integral multiple of De–Broglie wavelength associated with the electron, $2\pi r = n\lambda$



$\because\ \lambda = \frac{h}{mv}$ and $2\pi r = n\lambda \therefore\ mvr = \frac{nh}{2\pi}$

This is the Bohr quantizations condition.


equivalent straightened orbit

Ex. Find the initial momentum of electron if the momentum of electron is changed by p_m and the De Broglie wavelength associated with it changes by 0.50 %

Sol. $\frac{d\lambda}{\lambda}\times 100 = 0.5 \Rightarrow \frac{d\lambda}{\lambda} = \frac{0.5}{100} = \frac{1}{200}$ and $\Delta p = p_m$

$\because p = \frac{h}{\lambda}$, differentiating $\frac{dp}{d\lambda} = -\frac{h}{\lambda^2} = -\frac{h}{\lambda}\times\frac{1}{\lambda} = -\frac{p}{\lambda} \Rightarrow \frac{|dp|}{p} = \frac{d\lambda}{\lambda}$ $\therefore$ $\frac{p_m}{p} = \frac{1}{200} \Rightarrow p = 200\, p_m$

Ex. An α–particle moves in circular path of radius 0.83 cm in the presence of a magnetic field of 0.25 Wb/m^2. Find the De Broglie wavelength associated with the particle.

Sol. $\lambda = \frac{h}{p} = \frac{h}{qBr} = \frac{6.62\times10^{-34}}{2\times1.6\times10^{-19}\times0.25\times83\times10^{-4}}$ meter = 0.01 Å $\left[\because \frac{mv^2}{r} = qvB\right]$

Ex. A proton and an α–particle are accelerated through same potential difference. Find the ratio of their de- Broglie wavelength.

Sol. $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$ $[\because E = qV]$ For proton m_p = m, q = e

For α–particle m_α =4 m, q = 2e, $\frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p q_p}{m_\alpha q_\alpha}} = \frac{1}{2\sqrt{2}}$

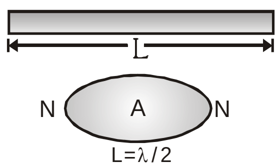
Ex. A particle of mass m is confined to a narrow tube of length L.

(a) Find the wavelengths of the de–Broglie wave which will resonate in the tube.

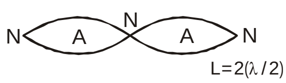
(b) Calculate the corresponding particle momenta, and

(c) Calculate the corresponding energies.

Sol. (a) The de–Broglie waves will resonate with a node at each end of the tube.

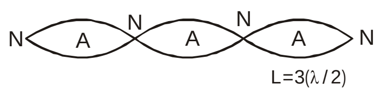


Few of the possible resonance forms are as follows : $\lambda_n = \frac{2L}{n}$, n=1,2,3.....

(b) 

Since de–Broglie wavelengths are $\lambda_n = \frac{h}{p_n}$

$p_n = \frac{h}{\lambda_n} = \frac{nh}{2L}$, n = 1,2,3....



(c) The kinetic energy of the particles are $K_n = \frac{p_n^2}{2m} = \frac{n^2h^2}{8L^2m}$, n = 1, 2, 3,....

ATOMIC STRUCTURE

VARIOUS MODELS FOR STRUCTURE OF ATOM

- **Dalton's Theory**

  Every material is composed of minute particles known as atom. Atom is indivisible i.e. it cannot be subdivided. It can neither be created nor be destroyed.

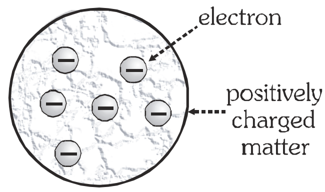
  All atoms of same element are identical physically as well as chemically, whereas atoms of different elements are different in properties.

  The atoms of different elements are made up of hydrogen atoms. (The radius of the heaviest atom is about 10 times that of hydrogen atom and its mass is about 250 times that of hydrogen).

  The atom is stable and electrically neutral.

- **Thomson's Atom Model**

  The atom as a whole is electrically neutral because the positive charge present on the atom (sphere) is equal to the negative charge of electrons present in the sphere.

  Atom is a positively charged sphere of radius 10^{-10} m in which electrons are embedded in between.

  The positive charge and the whole mass of the atom is uniformly distributed throughout the sphere.

- **Shortcomings of Thomson's model**

  (i) The spectrum of atoms cannot be explained with the help of this model

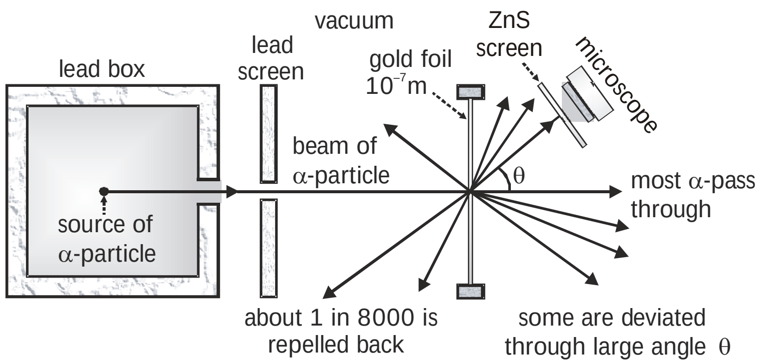
  (ii) Scattering of α–particles cannot be explained with the help of this model

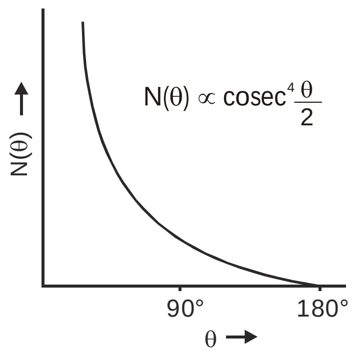
  (iii) Angular frequency of electron in n^{th} orbit $\omega_n = \dfrac{8\pi^2 k^2 Z^2 e^4 m}{n^3 h^3} \Rightarrow \omega_n \propto \dfrac{Z^2 m}{n^3}$

RUTHERFORD ATOM MODEL

- **Rutherford experiments on scattering of α – particles by thin gold foil**

  The experimental arrangement is shown in figure. α–particles are emitted by some radioactive material (polonium), kept inside a thick lead box. A very fine beam of α–particles passes through a small hole in the lead screen. This well collimated beam is then allowed to fall on a thin gold foil. While passing through the gold foil, α–particles are scattered through different angles. A zinc sulphide screen was placed out the other side of the gold foil. This screen was movable, so as to receive the α–particles, scattered from the gold foil at angles varying from 0 to 180°. When an α–particle strikes the screen, it produces a flash of light and it is observed by the microscope. It was found that :





- Most of the α – particles went straight through the gold foil and produced flashes on the screen as if there were nothing inside gold foil. Thus the atom is hollow.
- Few particles collided with the atoms of the foil which have scattered or deflected through considerable large angles. Few particles even turned back towards source itself.
- The entire positive charge and almost whole mass of the atom is concentrated in small centre called a nucleus.
- The electrons could not deflected the path of a α – particles i.e. electrons are very light.
- Electrons revolve round the nucleus in circular orbits. So, Rutherford 1911, proposed a new type of model of the atom. According to this model, the positive charge of the atom, instead of being uniformly distributed throughout a sphere of atomic dimension is concentrated in a very small volume (Less than 10^{-13}m is diameter) at it centre. This central core, now called nucleus, is surrounded by clouds of electron makes.

  The entire atom electrically neutral. According to Rutherford scattering formula, the number of α – particle scattered at an angle θ by a target are given by

$$N_\theta = \frac{N_0 nt(2Ze^2)^2}{16(4\pi\varepsilon_0)^2 r^2 (mv_0^2)^2} \times \frac{1}{\sin^4 \frac{\theta}{2}}$$

Where N_0 = number of α – particles that strike the unit area of the scatter

n = Number of target atom per m^3

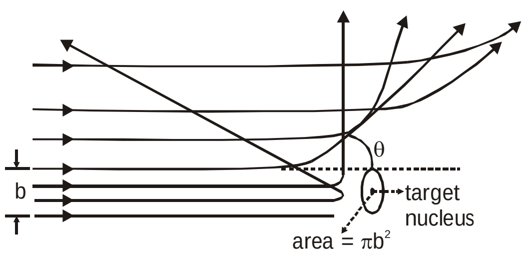
t = Thickness of target

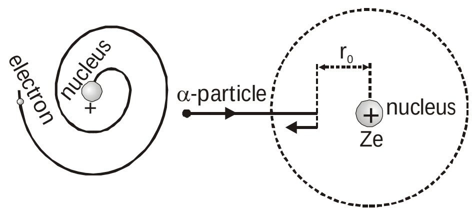
Ze = Charge on the target nucleus

2e = Charge on α – particle

r = Distance of the screen from target

v_0 = Velocity of α – particles at nearer distance of approach the size of a nucleus or the distance of nearer approach is given by.





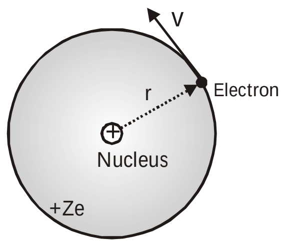
$$r_0 = \frac{1}{4\pi\varepsilon_0} \times \frac{(2Ze)^2}{\left[\frac{1}{2}mv_0^2\right]} = \frac{1}{4\pi \in_0} \frac{(2Ze)^2}{E_K}$$ where E_K = K.E. of α–particle

Bohr's Atomic Model

In 1913 Neils Bohr, a Danish Physicist, introduced a revolutionary concept i.e., the quantum concept to explain the stability of an atom. He made a simple but bold statement that "The old classical laws which are applicable to bigger bodies cannot be directly applied to the sub–atomic particles such as electrons or protons.

Bohr incorporated the following new ideas now regarded as postulates of Bohr's theory.

1. The centripetal force required for an encircling electron is provided by the electrostatic attraction between the nucleus and the electron i.e. $\frac{1}{4\pi\varepsilon_0}\frac{(Ze)e}{r^2} = \frac{mv^2}{r}$ ...(i)



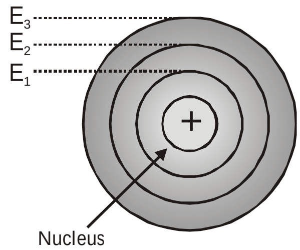
ε_0 =Absolute permittivity of free space = 8.85×10^{-12} $C^2\ N^{-1}\ m^{-2}$
m = Mass of electron
v = Velocity (linear) of electron
r = Radius of the orbit in which electron is revolving.
Z = Atomic number of hydrogen like atom.

2. Electrons can revolve only in those orbits in which angular momentum of electron about nucleus is an integral multiple of $\frac{h}{2\pi}$. i.e., $mvr = \frac{nh}{2\pi}$ ...(ii)

n = Principal quantum number of the orbit in which electron is revolving.

3. Electrons in an atom can revolve only in discrete circular orbits called stationary energy levels (shells). An electron in a shell is characterised by a definite energy, angular momentum and orbit number. While in any of these orbits, an electron does not radiate energy although it is accelerated.

4. Electrons in outer orbits have greater energy than those in inner orbits. The orbiting electron emits energy when it jumps from an outer orbit (higher energy states) to an inner orbit (lower energy states) and also absorbs energy when it jumps from an inner orbit to an outer orbit. $E_n - E_m = h\nu_{n,m}$



where, E_n = Outer energy state
E_m = Inner energy state
$\nu_{n,m}$ = Frequency of radiation

5. The energy absorbed or released is always in the form of electromagnetic radiations.

MATHEMATICAL ANALYSIS OF BOHR'S THEORY

From above equation (i) and (ii) i.e., $\frac{1}{4\pi\varepsilon_0}\frac{(Ze)e}{r^2} = \frac{mv^2}{r}$ and $mvr = \frac{nh}{2\pi}$ ...(ii)

We get the following results.

1. **Velocity of electron in nth orbit :** By putting the value of mvr in equation (i) from (ii) we get

$$\frac{1}{4\pi\varepsilon_0}Ze^2 = \left(\frac{nh}{2\pi}\right)\times v \Rightarrow v = \frac{Z}{n}\left[\frac{e^2}{2\varepsilon_0 h}\right] = \frac{Z}{n}v_0 \text{ ....(iii)}$$

Where, $v_0 = \frac{(1.6\times10^{-19})^2}{2\times8.85\times10^{-12}\times6.625\times10^{-34}}$ = 2.189×10^6 ms^{-1} = $\frac{c}{137}$ = 2.2×10^6 m/s

where $c = 3 \times 10^8$ m/s = speed of light in vacuum

2. **Radius of the nth orbit :**

From equation (iii), putting the value of v in equation (ii), we get

$$m\left(\frac{Z}{n}\times\frac{e^2}{2\varepsilon_0 h}\right)r = \frac{nh}{2\pi} \Rightarrow r = \frac{n^2}{Z}\left[\frac{\varepsilon_0 h^2}{\pi me^2}\right] = \frac{n^2}{Z}r_0 \text{ ...(iv)}$$

where $r_0 = \dfrac{8.85\times10^{-12}\times\left(6.625\times10^{-34}\right)^2}{3.14\times9.11\times10^{-31}\times\left(1.6\times10^{-19}\right)^2} = 0.529 \times 10^{-10}$ m ≈ 0.53Å

3. Total energy of electron in nth orbit :

From equation (i) K.E. = $\dfrac{1}{2}mv^2 = \dfrac{Ze^2}{8\pi\varepsilon_0 r}$ and PE = $\dfrac{1}{4\pi\varepsilon_0}\dfrac{(Ze)(-e)}{r} = -2\text{K.E.}$ $\therefore$ |PE| = 2 KE

Total energy of the system E = KE + PE = –2KE + KE = – KE = $\dfrac{-Ze^2}{8\pi\varepsilon_0 r}$

By putting the value of r from the equation (iv), we get E = $\dfrac{Z^2}{n^2}\left(-\dfrac{me^4}{8\varepsilon_0^2h^2}\right) = \dfrac{Z^2}{n^2}\cdot E_0$ ...(v)

where $E_0 = \dfrac{-\left(9.11\times10^{-3}\right)\left(1.6\times10^{-19}\right)^4}{8\times\left(8.85\times10^{-12}\right)^2\times\left(6.625\times10^{-34}\right)^2} = -13.6$ eV

4. Time period of revolution of electron in nth orbit : $T = \dfrac{2\pi r}{v}$

By putting the values of r and v, from (iii) and (iv) $T = \dfrac{n^3}{Z^2}\times\left(\dfrac{4\in_0^2h^3}{me^4}\right) = \dfrac{n^3}{Z^2}\cdot T_0$

where, $T_0 = \dfrac{4\times\left(8.85\times10^{-12}\right)^2\times\left(6.625\times10^{-34}\right)^3}{9.11\times10^{-31}\times\left(1.6\times10^{-19}\right)^4} = 1.51\times10^{-16}$ second

5. Frequency of revolution in nth orbit :

$f = \dfrac{1}{T} = \dfrac{Z^2}{n^3}\times\dfrac{me^4}{4\varepsilon_0^2h^3} = \dfrac{Z^2}{n^3}\cdot f_0$ where, $f_0 = \dfrac{9.11\times10^{-31}\times\left(1.6\times10^{-19}\right)^4}{4\times\left(8.85\times10^{-12}\right)^2\left(6.625\times10^{-34}\right)^3} = 6.6\times10^{15}$ Hz

6. Wavelength of photon

$$\Delta E = E_{n_2} - E_{n_1} = \frac{me^4}{8\varepsilon_0^2h^2}\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]Z^2 = 13.6\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]Z^2 \Rightarrow \Delta E = \frac{hc}{\lambda} \Rightarrow \frac{1}{\lambda} = \bar{\nu} = \frac{me^4}{8\varepsilon_0^2h^3c}\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]Z^2$$

$= R_\infty\left[\dfrac{1}{n_1^2}-\dfrac{1}{n_2^2}\right]Z^2$ where, $\bar{\nu}$ is called wave number. $R_\infty = R_H$ = Rydberg constant

$= \dfrac{9.11\times10^{-31}\times\left(1.6\times10^{-19}\right)^4}{8\times\left(8.85\times10^{-12}\right)^2\left(6.625\times10^{-34}\right)^3\times3\times10^8} = 1.097\times10^7\ \text{m}^{-1} = 1.097\times10^{-3}$ Å^{-1} (for stationary nucleus).

If nucleus is not stationary (i.e., mass of nucleus is not much greater than the mass of the revolving particle like electron), then $R = \dfrac{R_\infty}{1+m/M}$ where, m = mass of revolving particle and M = mass of nucleus

SPECTRAL SERIES OF HYDROGEN ATOM

It has been shown that the energy of the outer orbit is greater than the energy of the inner ones. When the Hydrogen atom is subjected to external energy, the electron jumps from lower energy state i.e. the hydrogen atom is excited. The excited state is unstable hence the electron return to its ground state in about 10^{-8} sec. The excess of energy is now radiated in the form of radiations of different wavelength. The different wavelength constitute spectral series. Which are characteristic of atom emitting, then the wave length of different members of series can be found from the following relations

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

This relation explains the complete spectrum of hydrogen. A detailed account of the important radiations are listed below.

- **Lyman Series** : The series consist of wavelength which are emitted when electron jumps from an outer orbits to the first orbit i. e., the electronic jumps to K orbit give rise to lyman series. Here n_1 = 1 & n_2 = 2, 3, 4, ...∞

  The wavelengths of different members of Lyman series are :
- **First member** : In this case n_1 = 1 and n_2 = 2

  hence $\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right] = \frac{3R}{4} \Rightarrow \lambda = \frac{4}{3R} \Rightarrow \lambda = \frac{4}{3 \times 10.97 \times 10^6}$ = 1216 × 10^{-10} m = 1216Å
- **Second member :** In this case n_1 = 1 and n_2 = 3 hence

  $\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{3^2}\right] = \frac{8R}{9} \Rightarrow \lambda = \frac{9}{8R} \Rightarrow \lambda = \frac{9}{8 \times 10.97 \times 10^6}$ = 1026 × 10^{-10} m =1026Å

  Similarly the wavelength of the other members can be calculated.
- **Limiting members** : In this case n_1 = 1 and n_2 = ∞ , hence

  $\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{\infty^2}\right] = R \Rightarrow \lambda = \frac{1}{R} \Rightarrow \lambda = \frac{1}{10.97 \times 10^6}$ = 912 × 10^{-10}m = 912Å

  This series lies in ultraviolet region.
- **Balmer Series :** This series is consist of all wave lengths which are emitted when an electron jumps from an outer orbit to the second orbit i. e., the electron jumps to L orbit give rise to Balmer series. Here n_1 = 2 and n_2 = 3, 4, 5 ....∞ The wavelength of different members of Balmer series.
- **First member** : In this case n_1 = 2 and n_2 = 3, hence

  $\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = \frac{5R}{36} \Rightarrow \lambda = \frac{36}{5R} \Rightarrow \lambda = \frac{36}{5 \times 10.97 \times 10^6}$ = 6563 × 10^{-10}m = 6563Å
- **Second member** : In this case n_1 = 2 and n_2 = 4, hence.

  $\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{4^2}\right] = \frac{3R}{16} \Rightarrow \lambda = \frac{16}{3R} \Rightarrow \lambda = \frac{16}{3 \times 10.97 \times 10^6}$ = 4861 × 10^{-10}m = 4861Å
- **Limiting members**: In this case n_1 = 2 and n_2 = ∞ , hence $\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{\infty}\right] = \frac{R}{4} \Rightarrow \lambda = \frac{4}{R}$ = 3646Å

  This series lies in visible and near ultravoilet region.

- **Paschen Series :** This series consist of all wavelength are emitted when an electron jumps from an outer orbit to the third orbit i. e., the electron jumps to M orbit give rise to paschen series. Here n_1=3 & n_2= 4, 5, 6 ....∞. The different wavelengths of this series can be obtained from the formula $\frac{1}{\lambda} = R\left[\frac{1}{3^2} - \frac{1}{n_2^2}\right]$

  where n_2 = 4, 5, 6 ....∞
  For the first member, the wavelengths is 18750Å. This series lies in infra–red region.
- **Brackett Series :** This series is consist of all wavelengths which are emitted when an electron jumps from an outer orbits to the fourth orbit i. e., the electron jumps to N orbit give rise to Brackett series. Here n_1 = 4 & n_2 = 5, 6, 7, ...∞.

  The different wavelengths of this series can be obtained from the formula $\frac{1}{\lambda} = R\left[\frac{1}{4^2} - \frac{1}{n_2^2}\right]$

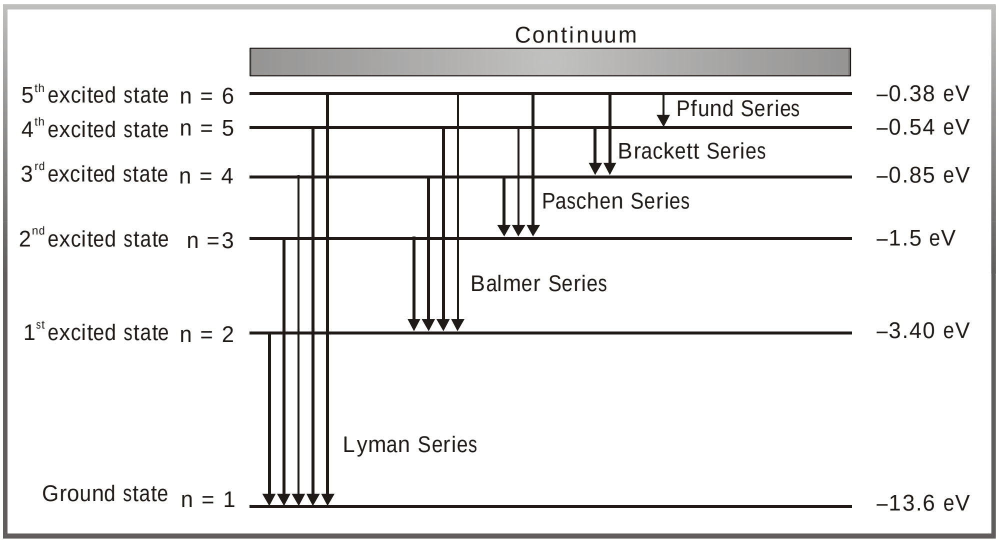
  where n_2 = 5, 6, 7 ....∞
  This series lies in infra–red region of spectrum.
- **Pfund series :** The series consist of all wavelengths which are emitted when an electron jumps from an outer orbit to the fifth orbit i. e., the electron jumps to O orbit give right to Pfund series. Here n_1 = 5 and n_2 = 6, 7, 8 ....∞.

  The different wavelengths of this series can be obtained from the formula $\frac{1}{\lambda} = R\left[\frac{1}{5^2} - \frac{1}{n_2^2}\right]$

  where n_2 = 6, 7, 8 ....∞
  This series lies in infra–red region of spectrum.

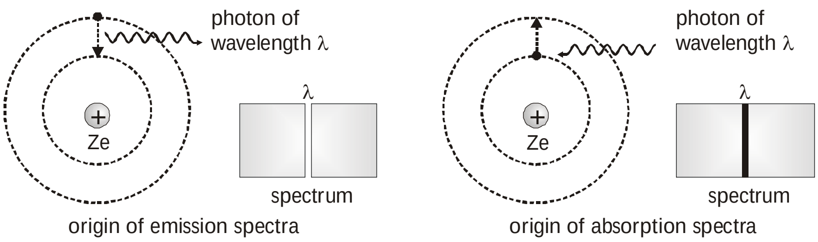
The result are tabulated below

S. No.	Series Observed	Value of n_1	Value of n_2	Position in the Spectrum
1.	Lyman Series	1	2,3,4...∞	Ultra Voilet
2.	Balmer Series	2	3,4,5...∞	Visible
3.	Paschen Series	3	4,5,6....∞	Infra–red
4.	Brackett Series	4	5,6,7....∞	Infra–red
5.	Pfund Series	5	6,7,8....∞	Infra–red



EXCITATION AND IONISATION OF ATOMS

Consider the case of simplest atom i. e., hydrogen atom, this has one electron in the innermost orbit i.e., (n = 1) and is said to be in the unexcited or normal state. If by some means, sufficient energy is supplied to the electron. It moves to higher energy states. When the atom is in a state of a high energy it is said to be excited. The process of raising or transferring the electron from lower energy state is called excitation. When by the process of excitation, the electron is completely removed from the atom. The atom is said to be ionized. Now the atom has left with a positive charge. Thus the process of raising the atom from the normal state to the ionized state is called ionisation. The process of excitation and ionisation both are absorption phenomena. The excited state is not stationary state and lasts in a very short interval of time (10^{-8} sec) because the electron under the attractive force of the nucleus jumps to the lower permitted orbit. This is accompanied by the emission of radiation according to BOHR'S frequency condition.



The energy necessary to excite an atom can be supplied in a number of ways. The most commonly kinetic energy (Wholly or partly) of the electrons is transferred to the atom. The atom is now in a excited state. The minimum potential V required to accelerate the bombarding electrons to cause excitation from the ground state is called the resonance potential. The various values of potential to cause excitation of higher state called **excitation potential**. The potential necessary to accelerate the bombarding electrons to cause ionisation is called the **ionization potential**. The term critical potential is used to include the resonance, excitation and ionisation potential. We have seen that the energy required to excite the electron from first to second state is 13.6 – 3.4 = 10.2 eV. from first to third state is 13.6 – 1.5 = 12.1 eV., and so on. The energy required to ionise hydrogen atom is 0 – (– 13.6) = 13.6 eV. Hence ionization potential of hydrogen atom is 13.6 volt.

SUCCESSES AND LIMITATIONS

Bohr showed that Planck's quantum ideas were a necessary element of the atomic theory. He introduced the idea of quantized energy levels and explained the emission or absorption of radiations as being due to the transition of an electron from one level to another. As a model for even multielectron atoms, the Bohr picture is still useful. It leads to a good, simple, rational ordering of the electrons in larger atoms and quantitatively helps to predict a greater deal about chemical behavior and spectral detail.

Bohr's theory is unable to explain the following facts :

- The spectral lines of hydrogen atom are not single lines but each one is a collection of several closely spaced lines.
- The structure of multielectron atoms is not explained.
- No explanation for using the principles of quantization of angular momentum.
- No explanation for Zeeman effect. If a substance which gives a line emission spectrum is placed in a

magnetic field, the lines of the spectrum get splitted up into a number of closely spaced lines. This phenomenon is known as Zeeman effect.

Ex. A hydrogen like atom of atomic number Z is in an excited state of quantum number 2n. It can emit a maximum energy photon of 204 eV. If it makes a transition to quantum state n, a photon of energy 40.8 eV is emitted. Find n, Z and the ground state energy (in eV) for this atom. Also, calculate the minimum energy (in eV) that can be emitted by this atom during de–excitation. Ground state energy of hydrogen atom is –13.6 eV.

Sol. The energy released during de–excitation in hydrogen like atoms is given by :

$$E_{n_2}-E_{n_1}=\frac{me^4}{8\varepsilon_0^2h^2}\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]Z^2$$

Energy released in de–excitation will be maximum if transition takes place from nth energy level to ground state i.e.,

$$E_{2n}-E_1=13.6\left[\frac{1}{1^2}-\frac{1}{(2n)^2}\right]Z^2 = 204\text{ eV} \ldots\text{(i)} \ \& \ \text{also } E_{2n}-E_n=13.6\left[\frac{1}{n^2}-\frac{1}{(2n)^2}\right]Z^2 = 40.8\text{ eV} \ldots\text{(ii)}$$

Taking ratio of (i) to (ii), we will get $\frac{4n^2-1}{3}=5 \Rightarrow n^2=4 \Rightarrow n=2$

Putting n=2 in equation (i) we get

$Z^2=\frac{204\times16}{13.6\times15} \Rightarrow Z=4 \because E_n=-13.6\ \frac{Z^2}{n^2} \Rightarrow E_1=-13.6\times\frac{4^2}{1^2}=-217.6$ eV = ground state energy

ΔE is minimum if transition will be from 2n to 2n–1 i.e. between last two adjacent energy levels.

$$\therefore \Delta E_{min}=E_{2n}-E_{2n-1}=13.6\left[\frac{1}{3^2}-\frac{1}{4^2}\right]4^2=10.57\text{ eV}$$

is the minimum amount of energy released during de–excitation.

Ex. A single electron orbits around a stationary nucleus of charge +Ze where Z is a constant and e is the magnitude of electronic charge. It requires 47.2 eV to excite the electron from the second orbit to third orbit. Find

(i) The value of Z

(ii) The energy required to excite the electron from the third to the fourth Bohr orbit

(iii) The wavelength of electronic radiation required to remove the electron from first Bohr orbit to infinity

(iv) Find the K.E., P.E. and angular momentum of electron in the 1st Bohr orbit.

[The ionization energy of hydrogen atom = 13.6 eV, Bohr radius = 5.3×10^{-11} m, Velocity of light = 3×10^8 m/s. Planck's constant = 6.6×10^{-34} J–s]

Sol. The energy required to excite the electron from n_1 to n_2 orbit revolving around the nucleus with charge +Ze is given by $E_{n_2}-E_{n_1}=\frac{me^4}{8\varepsilon_0^2h^2}\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]Z^2 \Rightarrow E_{n_2}-E_{n_1}=Z^2\times(13.6)\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$

(i) Since 47.2 eV energy is required to excite the electron from $n_1=2$ to $n_2=3$ orbit

$$47.2 = Z^2 \times 13.6\left[\frac{1}{2^2}-\frac{1}{3^2}\right] \Rightarrow Z^2 = \frac{47.2\times 36}{13.6\times 5} = 24.988 \approx 25 \Rightarrow Z=5$$

(ii) The energy required to excite the electron from n_1 =3 to n_2 =4 is given by

$$E_4 - E_3 = 13.6\ Z^2{=}5\left[\frac{1}{3^2}-\frac{1}{4^2}\right] = \frac{25\times 13.6\times 7}{144} = 16.53\ \text{eV}$$

(iii)The energy required to remove the electron from the first Bohr orbit to infinity (∞) is given by

$$E_\infty - E_3 = 13.6\times Z^2\left[\frac{1}{1^2}-\frac{1}{\infty^2}\right] = 13.6\times 25\text{eV} = 340\text{eV}$$

In order to calculate the wavelength of radiation, we use Bohr's frequency relation

$$hf = \frac{hc}{\lambda} = 13.6\times 25\times(1.6\times 10^{-19})\text{J} \Rightarrow \lambda = \frac{(6.6\times 10^{-34})\times 10^8\times 3}{13.6\times 25\times(1.6\times 10^{-19})} = 36.397\text{Å}$$

(iv)K.E. $= \frac{1}{2}mv_1^2 = \frac{1}{2}\times\frac{Ze^2}{4\pi g \in_0 r_1} = 543.4\times 10^{-19}$ J

P.E. = – 2 × K.E. = – 1086.8 × 10^{-19} J

Angular momentum = $mv_1r_1 = \frac{h}{2\pi} = 1.05\times 10^{-34}$ Js

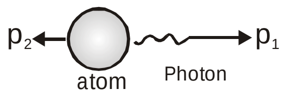
The radius r_1 of the first Bohr orbit is given by

$$r_1 = \frac{\varepsilon_0 h^2}{\pi m e^2}\cdot\frac{1}{Z} = \frac{0.53\times 10^{-10}}{5}\left(\because \frac{\varepsilon_0 h^2}{\pi m e^2} = 0.53\times 10^{-10}\text{m}\right) = 1.106\times 10^{-10}\text{ m} = 0.106\text{ Å}$$

Ex. An isolated hydrogen atom emits a photon of 10.2 eV.
(i) Determine the momentum of photon emitted (ii) Calculate the recoil momentum of the atom
(iii) Find the kinetic energy of the recoil atom [Mass of proton= m_p = 1.67 × 10^{-27} kg]

Sol. (i) Momentum of the photon is $p_1 = \frac{E}{c} = \frac{10.2\times 1.6\times 10^{-19}}{3\times 10^8}$ = 5.44 × 10^{-27} kg–m/s

(ii) Applying the momentum conservation



$p_2 = p_1$ = 5.44 × 10^{-27} kg–m/s

(iii) K = $\frac{1}{2}mv^2$ (v = recoil speed of atom, m = mass of hydrogen atom) $K = \frac{1}{2}m\left(\frac{p}{m}\right)^2 = \frac{p^2}{2m}$

Substituting the value of the momentum of atom, we get $K = \frac{(5.44\times 10^{-27})^2}{2\times 1.67\times 10^{-27}}$ = 8.86 × 10^{-27}J

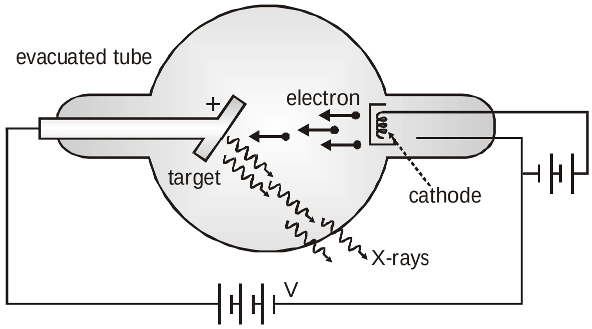
Physical quantity **Formula** **Ratio Formulae of hydrogen atom**

Radius of Bohr orbit (r_n)	$r_n = \frac{n^2h^2}{4\pi^2mkZe^2}$; $r_n = 0.53\frac{n^2}{Z}$ Å	$r_1 : r_2 : r_3 ... r_n = 1:4:9...n^2$
Velocity of electron in n^{th} Bohr orbit (v_n)	$v_n = \frac{2\pi kZe^2}{nh}$; $v_n = 2.2 \times 10^6 \frac{Z}{n}$	$v_1 : v_2 : v_3 ... v_n = 1 : \frac{1}{2} : \frac{1}{3} ... \frac{1}{n}$
Momentum of electron (p_n)	$p_n = \frac{2\pi mke^2z}{nh}$; $p_n \propto \frac{Z}{n}$	$p_1 : p_2 : p_3 ... p_n = 1 : \frac{1}{2} : \frac{1}{3} ... \frac{1}{n}$
Angular velocity of electron(ω_n)	$\omega_n = \frac{8\pi^3k^2Z^2mc^4}{n^3h^3}$; $\omega_n \propto \frac{Z^2}{n^3}$	$\omega_1 : \omega_2 : \omega_3 ... \omega_n = 1 : \frac{1}{8} : \frac{1}{27} ... \frac{1}{n^3}$
Time Period of electron (T_n)	$T_n = \frac{n^3h^3}{4\pi^2k^2Z^2me^4}$; $T_n \propto \frac{n^3}{Z^2}$	$T_1 : T_2 : T_3 ... T_n = 1:8:27: ... :n^3$
Frequency (f_n)	$f_n = \frac{4\pi^2k^2Z^2e^4m}{n^3h^3}$; $f_n \propto \frac{Z^2}{n^3}$	$f_1 : f_2 : f_3 ... f_n = 1 : \frac{1}{8} : \frac{1}{27} ... \frac{1}{n^3}$
Orbital current (I_n)	$I_n = \frac{4\pi^2k^2Z^2me^5}{n^3h^3}$; $I_n \propto \frac{Z^2}{n^3}$	$I_1 : I_2 : I_3 ... I_n = 1 : \frac{1}{8} : \frac{1}{27} ... \frac{1}{n^3}$
Angular momentum (J_n)	$J_n = \frac{nh}{2\pi}$; $J_n \propto n$	$J_1 : J_2 : J_3 ... J_n = 1 : 2 : 3...n$
Centripetal acceleration (a_n)	$a_n = \frac{16\pi^4k^3Z^3me^6}{n^4h^4}$; $a_n \propto \frac{Z^3}{n^4}$	$a_1 : a_2 : a_3 ... a_n = 1 : \frac{1}{16} : \frac{1}{81} ... \frac{1}{n^4}$
Kinetic energy (E_{K_n})	$E_{K_n} = \frac{RchZ^2}{n^2}$; $E_{K_n} \propto \frac{Z^2}{n^2}$	$E_{K_1} : E_{K_2} ... E_{K_n} = 1 : \frac{1}{4} : \frac{1}{9} ... \frac{1}{n^2}$
Potential energy (U_n)	$U_n = \frac{-2RchZ^2}{n^2}$; $U_n \propto \frac{Z^2}{n^2}$	$U_1 : U_2 : U_3 ... U_n = 1 : \frac{1}{4} : \frac{1}{9} ... \frac{1}{n^2}$
Total energy (E_n)	$E_n = \frac{-RchZ^2}{n^2}$; $E_n \propto \frac{Z^2}{n^2}$	$E_1 : E_2 : E_3 ... E_n = 1 : \frac{1}{4} : \frac{1}{9} ... \frac{1}{n^2}$

X–RAYS

ROENTGEN EXPERIMENT

Roentgen discovered X–ray. While performing experiment on electric discharge tube Roentgen observed that when pressure inside the tube is 10^{-3}mm of Hg and applied potential is kept 25kV then some unknown radiation are emitted by anode. These are known as X–ray. X–rays are produced by bombarding high speed electrons on a target of high atomic weight and high melting point.



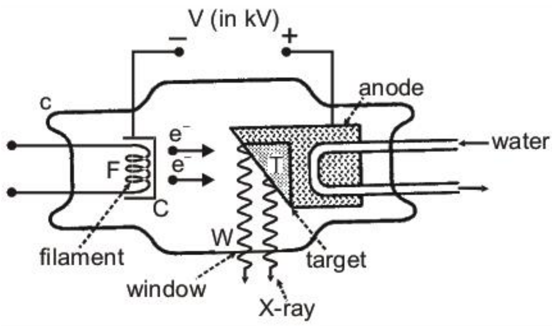
To Produce X–ray Three Things are Required

(i) Source of electron (ii) Means of accelerating these electron to high speed

(iii) Target on which these high speed electron strike

COOLIDGE METHOD

Coolidge developed thermoionic vacuum X–ray tube in which electron are produced by thermoionic emission method. Due to high potential difference electrons (emitted due to thermoionic method) move towards the target and strike from the atom of target due to which X–ray are produced. Experimentally it is observed that only 1% or 2% kinetic energy of electron beam is used to produce X–ray. Rest of energy is wasted in form of heat.



Characteristics of target

(a) Must have high atomic number to produce hard X–rays.

(b) High melting point to withstand high temperature produced.

(c) High thermal conductivity to remove the heat produced

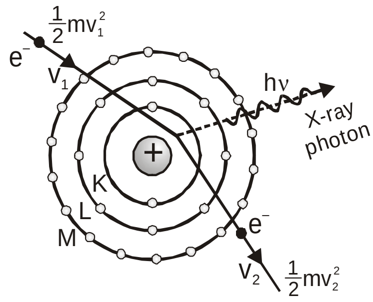
(d) Tantalum, platinum, molybdenum and tungsten serve as target materials

- **Control of intensity** : The intensity of X–ray depends on number of electrons striking the target and number of electron depend on temperature of filament which can be controlled by filament current. Thus intensity of X–ray depends on current flowing through filament.

- **Control of Penetrating Power**: The Penetrating power of X–ray depends on the energy of incident electron. The energy of electron can be controlled by applied potential difference. Thus penetrating power of X–ray depend on applied potential difference. Thus the intensity of X–ray depends on current flowing through filament while penetrating power depends on applied potential difference

	Soft X–ray	**Hard X–ray**
Wavelength	10 Å to 100 Å	0.1 Å – 10 Å
Energy	$\frac{12400}{\lambda}$ eV–Å	$\frac{12400}{\lambda}$ eV–Å
Penetrating power	Less	More
Use	Radio photography	Radio therapy

- **Continuous spectrum of X–ray** : When high speed electron collides from the atom of target and passes close to the nucleus.There is coulomb attractive force due to this electron is deaccelerated i.e. energy is decreased. The loss of energy during deacceleration is emitted in the form of X–rays. X–ray produced in this way are called Braking or Bremstralung radiation and form continuous spectrum. In continuous spectrum of X–ray all the wavelength of X–ray are present but below a minimum value of wavelength there is no X–ray. It is called cut off or threshold or minimum wavelength of X–ray. The minimum wavelength depends on applied potential.



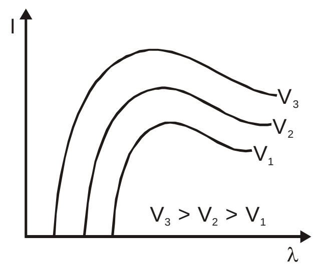
- **Loss in Kinetic Energy**

$\frac{1}{2}mv_1^2 - \frac{1}{2}mv_2^2 = h\nu$ + heat energy if $v_2 = 0$, $v_1 = v$

(In first collision, heat = 0)

$\frac{1}{2}mv^2 = h\nu_{max}$ ...(i)

$\frac{1}{2}mv^2 = eV$ ...(ii) [here V is applied potential]

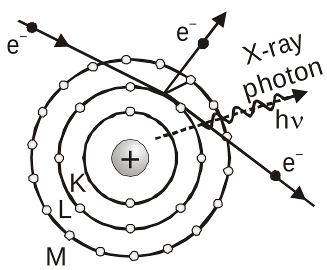


from (i) and (ii) $h\nu_{max} = eV \Rightarrow \frac{hc}{\lambda_{min}} = eV \Rightarrow \lambda_{min} = \frac{12400}{V} \times$ volt $= \frac{12400}{V} \times 10^{-10}$ m × volt

Continuous X–rays also known as white X–ray. Minimum wavelength of these spectrum only depends on applied potential and doesn' t depend on atomic number.

- **Characteristic Spectrum of X–ray**

When the target of X–ray tube is collide by energetic electron it emits two type of X–ray radiation. One of them has a continuous spectrum whose wavelength depend on applied potential while other consists of spectral lines whose wavelength depend on nature of target. The radiation forming the line spectrum is called characteristic X–rays. When highly accelerated electron strikes with the atom of target then it knockout the electron of orbit, due to this a vacancy is created. To fill this vacancy electron jumps from higher energy level and electromagnetic radiation are emitted which form characteristic spectrum of X–ray. Whose wavelength depends on nature of target and not on applied potential.



From Bohr Model

$n_1 = 1,\quad n_2 = 2, 3, 4.......$K series

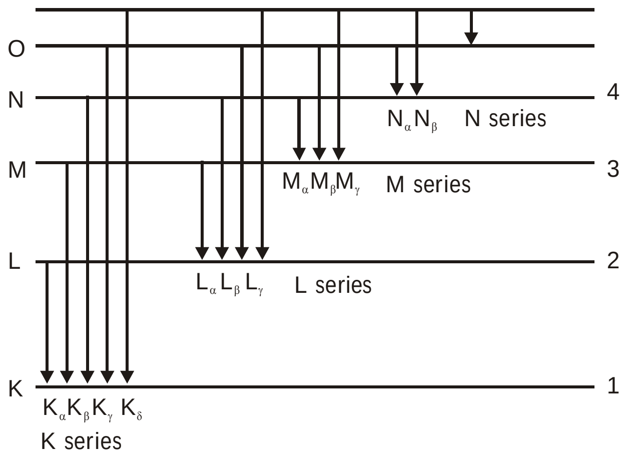
$n_1 = 2,\quad n_2 = 3, 4, 5.......$L series

$n_1 = 3,\quad n_2 = 4, 5, 6.......$M series

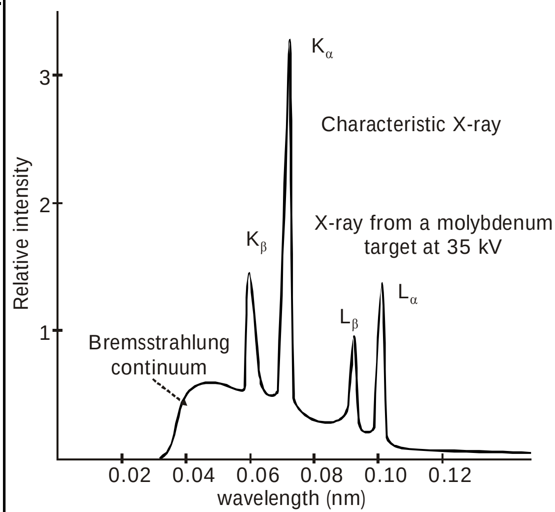
First line of series = α

Second line of series = β

Third line of series = γ



Transition	Wave–length	Energy	Energy difference	Wavelength
$L \to K$	$\lambda_{K\alpha}$	$h\nu_{K\alpha}$	$-(E_K - E_L)$	$\lambda_{K\alpha} = \frac{hc}{(E_K - E_L)}$
$(2 \to 1)$			$= h\nu_{K\alpha}$	$= \frac{12400}{(E_K - E_L)}$ eVÅ
$M \to K$	$\lambda_{K\beta}$	$h\nu_{K\beta}$	$-(E_K - E_M)$	$\lambda_{K\beta} = \frac{hc}{(E_K - E_M)}$
$(3 \to 1)$			$= h\nu_{K\beta}$	$= \frac{12400}{(E_K - E_M)}$ eVÅ
$M \to L$	$\lambda_{L\alpha}$	$h\nu_{L\alpha}$	$-(E_L - E_M)$	$\lambda_{L\alpha} = \frac{hc}{(E_L - E_M)}$
$(3 \to 2)$			$= h\nu_{L\alpha}$	$= \frac{12400}{(E_L - E_M)}$ eVÅ



MOSELEY'S LAW

Moseley studied the characteristic spectrum of number of many elements and observed that the square root of the frequency of a K– line is closely proportional to atomic number of the element. This is called Moseley's law.

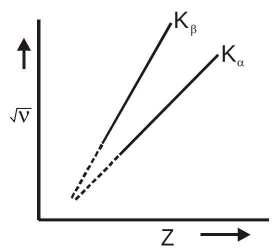
$$\sqrt{\nu} \propto (Z - b) \Rightarrow \nu \propto (Z - b)^2 \Rightarrow \nu = a(Z - b)^2 \quad ...(i)$$

Z = atomic number of target

ν = frequency of characteristic spectrum

b = screening constant (for K– series b=1, L series b=7.4)

a = proportionality constant



From Bohr Model $\quad \nu = RcZ^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] \quad ...(ii)$

Comparing (i) and (ii) $a = Rc\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

- Thus proportionality constant 'a' does not depend on the nature of target but depend on transition.

	Bohr model		**Moseley's correction**
1.	For single electron species	**1.**	For many electron species
2.	$\Delta E = 13.6Z^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ eV	**2.**	$\Delta E = 13.6\ (Z-1)^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ eV
3.	$\nu = RcZ^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$	**3.**	$\nu = Rc(Z-1)^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$
4.	$\frac{1}{\lambda} = RZ^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$	**4.**	$\frac{1}{\lambda} = R\ (Z-1)^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

- For X–ray production, Moseley formulae are used because heavy metal are used.

When target is same $\lambda \propto \dfrac{1}{\frac{1}{n_1^2} - \frac{1}{n_2^2}}$ **When transition is same** $\lambda \propto \dfrac{1}{(Z-b)^2}$

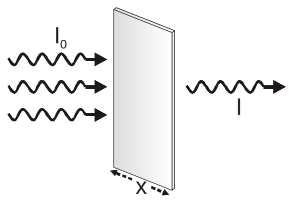
ABSORPTION OF X–RAY

When X–ray passes through x thickness then its intensity $I = I_0e^{-\mu x}$

I_0 = Intensity of incident X–ray

I = Intensity of X–ray after passing through x distance

μ = absorption coefficient of material



- Intensity of X–ray decrease exponentially.
- Maximum absorption of X–ray $\rightarrow$ Lead
- Minimum absorption of X–ray $\rightarrow$ Air

Half thickness ($x_{1/2}$)

The distance travelled by X–ray when intensity become half the original value $x_{1/2} = \dfrac{\ell n_2}{\mu}$

Ex. When X–rays of wavelength 0.5Å pass through 10 mm thick Al sheet then their intensity is reduced to one sixth. Find the absorption coefficient for Aluminium .

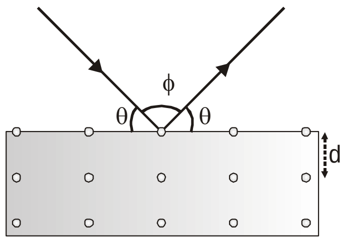
Sol. $\mu = \dfrac{2.303}{x} \log\left(\dfrac{I_o}{I}\right) = \dfrac{2.303}{10}\log_{10} 6 = \dfrac{2.303 \times 0.7781}{10} = 0.1752$ / mm

DIFFRACTION OF X–RAY

Diffraction of X–ray is possible by crystals because the interatomic spacing in a crystal lattice is order of wavelength of X–rays it was first verified by Lauve.

Diffraction of X–ray take place according to Bragg's law $2d \sin\theta = n\lambda$

d = spacing of crystal plane or lattice constant or distance between adjacent atomic plane



θ = Bragg's angle or glancing angle

ϕ = Diffracting angle n = 1, 2, 3 ....

For Maximum Wavelength

$\sin\theta = 1, n = 1 \Rightarrow \lambda_{max} = 2d$

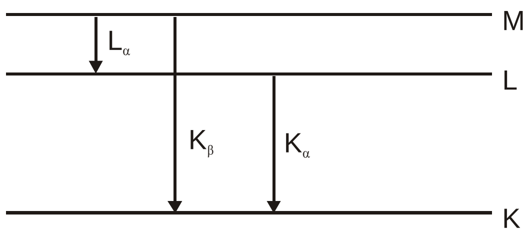
so if $\lambda > 2d$ diffraction is not possible i.e. solution of Bragg's equation is not possible.

PROPERTIES OF X–RAY

- X–ray always travel with the velocity of light in straight line because X–rays are em waves
- X–ray is electromagnetic radiation it show particle and wave both nature
- In reflection, diffraction, interference, refraction X–ray shows wave nature while in photoelectric effect it shows particle nature.
- There is no charge on X–ray thus these are not deflected by electric field and magnetic field.
- X–ray are invisible.
- X–ray affects the photographic plate
- When X–ray incidents on the surface of substance it exerts force and pressure and transfer energy and momentum
- Characteristic X–ray can not obtained from hydrogen because the difference of energy level in hydrogen is very small.

Ex. Show that the frequency of K_β X–ray of a material is equal to the sum of frequencies of K_α and L_α X–rays of the same material.

Sol. The energy level diagram of an atom with one electron knocked out is shown above.



Energy of K_α X–ray is $E_{K\alpha} = E_L - E_K$

and of K_β X–ray is $E_{K\beta} = E_M - E_K$

and of L_α X–rays is $E_{L\alpha} = E_M - E_L$

thus $E_{K\beta} = E_{K\alpha} + E_{L\alpha}$ or $\nu_{K\beta} = \nu_{K\alpha} + \nu_{L\alpha}$

EXERCISE (S-1)

Photoelectric Effect :

1. In an experiment on photoelectric effect, the slope of the cut-off voltage versus frequency of incident light is found to be 4.12×10^{-15} V s. Calculate the value of Planck's constant. **NCERT**

MP0001

2. A 100W sodium lamp radiates energy uniformly in all directions. The lamp is located at the centre of a large sphere that absorbs all the sodium light which is incident on it. The wavelength of the sodium light is 589 nm. (a) What is the energy per photon associated with the sodium light ? (b) At what rate are the photons delivered to the sphere? **NCERT**

MP0002

3. In a photoelctric experiment set up, photons of energy 5 eV fall on the cathode having work function 3 eV.

(a) If the saturation current is $i_A = 4\mu A$ for intensity 10^{-5} W/m^2, then plot a graph between anode potential and current.

(b) Also draw a graph for intensity of incident radiation of 2×10^{-5} W/m^2 . **[JEE' 2003]**

MP0003

4. Monochromatic radiation of wavelength 640.2 nm (1nm = 10^{-9} m) from a neon lamp irradiates photosensitive material made of cesium. The stopping voltage is measured to be 0.54 V. The source is replaced by an iron source and its 427.2 nm line irradiates the same photo-cell. Predict the new stopping voltage. **NCERT**

MP0004

5. Monochromatic light of wavelength 632.8 nm is produced by a helium-neon laser. The power emitted is 9.42 mW. **NCERT**

(a) Find the energy and momentum of each photon in the light beam,

(b) How many photons per second, on the average, arrive at a target irradiated by this beam? (Assume the beam to have uniform cross-section which is less than the target area), and

(c) How fast does a hydrogen atom have to travel in order to have the same momentum as that of the photon ?

MP0005

Wave Nature of Matter

6. Calculate the **NCERT**

(a) momentum, and

(b) de-Broglie wavelength of the electrons accelerated through a potential difference of 56 V.

MP0006

7. The wavelength of light from the spectral emission line of sodium is 589 nm. Find the kinetic energy at which **NCERT**

(a) an electron, and

(b) a neutron, would have the same de-Broglie wavelength.

MP0007

8. (a) For what kinetic energy of a neutron will the associated de-Broglie wavelength be 1.40×10^{-10} m?

(b) Also find the de-Broglie wavelength of a neutron, in thermal equilibrium with matter, having an average kinetic energy of (3/2) k T at 300 K. **NCERT**

MP0008

9. The potential energy of a particle varies as $U(x) = E_0$ for $0 \le x \le 1$ and $U(x) = 0$ for $x > 1$

For $0 \le x \le 1$. de–Broglie wavelengths is λ_1 and for $x > 1$ the de–Broglie wavelength is λ_2.

Total energy of the particle is $2E_0$. Find $\frac{\lambda_1}{\lambda_2}$. **[JEE 2005]**

MP0009

Bohr's Theory

10. Determine the number of lines in Paschen series which have a wavelength greater than 1000 nm.

MP0010

11. In a photoelectric setup, the radiations from the Balmer series of hydrogen atom are incident on a metal surface of work function 2eV. The wavelength of incident radiations lies between 450 nm to 700 nm. Find the maximum kinetic energy of photoelectron emitted. (Given hc/e = 1242 eV-nm). **[JEE-2004]**

MP0011

12. An electron and a proton are separated by a large distance and the electron approaches the proton with a kinetic energy of 4.11 eV. If the electron is captured by the proton to form hydrogen atom in the ground state, the wavelength of photon given off is $\alpha \times 10^2$ Å? Fill the value of α in your OMR sheet. **MP0012**

13. A neutron moving through container filled with stationary deuterons. The neutron successively collides elastically and head on with stationary deuterons one at a time. The mass of the neutron is equal to half that of the deuteron. How many such collision would be required to slow the neutron down from 81 eV to 1 eV. [Neglect the relativistic effect] **MP0013**

14. What is the shortest wavelength present in the Paschen series of spectral lines? **NCERT**

MP0014

15. A 12.5 eV electron beam is used to bombard gaseous hydrogen at room temperature. What series of wavelengths will be emitted? **NCERT**

MP0015

16. The total energy of an electron in the first excited state of the hydrogen atom is about –3.4 eV.
(a) What is the kinetic energy of the electron in this state? **NCERT**
(b) What is the potential energy of the electron in this state?
(c) Which of the answers above would change if the choice of the zero of potential energy is changed?

MP0016

17. Obtain the first Bohr's radius and the ground state energy of a muonic hydrogen atom [i.e., an atom in which a negatively charged muon (μ^-) of mass about $207m_e$ orbits around a proton]. **NCERT**

MP0017

18. A potential difference of V volts is applied on two parallel electrodes separated by a distance of 4.0×10^{-2} m . The electrons of very low energy are injected into the region between the electrodes which contains argon at low pressure . The average distance the electrons travel between collisions with argon atoms is 8×10^{-5} m . The ionization energy of argon atom is 16 eV . Estimate the minimum value of V(in kV) such that the electrons will cause ionization in argon atoms by collision.

MP0018

19. In hydrogen-like atom (Z = 11), n^{th} line of Lyman series has wavelength λ equal to the de-Broglie's wavelength of electron in the level from which it originated. What is the value of n? [Take: Bohr radius (r_0) = 0.53 Å and Rydberg constant (R) = 1.1×10^7 m^{-1}] **[JEE 2006]**
MP0019

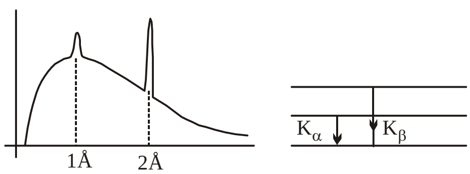
X-Rays

20. The wavelength of characteristic K_α-line emitted by a hydrogen like element is 2.5 Å. Find the wavelength of the K_γ-line emitted by the same element (in Å). [Assume the shielding effect to be same as of K_α] **MP0020**

21. In an accelerator experiment on high-energy collisions of electrons with positrons, a certain event is interpreted as annihilation of an electron-positron pair of total energy 10.2 BeV into two γ-rays of equal energy. What is the wavelength associated with each γ-ray? (1BeV = 10^9 eV) **NCERT**

MP0021

22. Figure shows K_α & K_β X-rays along with continuous X-ray. Find the energy of L_α X-ray. (Use hc = 12420 evÅ).



MP0022

23. A graph of $\sqrt{\nu}$ (where ν is the frequency of K_α line of the characteristic X-ray spectrum) is plotted against the atomic number Z of the elements emitting the characteristic X-ray .The intercept of the graph on the Z-axis is 1 and the slope of the graph is 0.5×10^8 S.I. units. The frequency of the K_α line for an element of atomic number 41 is given as $\alpha \times 10^{16}$ Hz. Find the value of α. **MP0023**

EXERCISE (S-2)

1. A cooling object was emitting radiations of time varying wavelength $\lambda = 3000 + 40t$, where λ is in Å and t is in second is incident on a metal sheet (of work function 2eV) such that the power incident on sheet is constant at 100 watt. This signal is switched on and off for time intervals of 2 minutes and 1 minute respectively. Each time the signal is switched on, λ again starts from fresh value of 3000 Å. If the metal plate is grounded so that it always remains neutral and electron clouding is negligible then find the maximum photocurrent(mA). The photoemission efficiency is 0.01% and remains constant.(Take hc=12400eV-Å) **MP0024**

2. A light of wavelength 3540 Å falls on a metal having work function of 2.5 eV. If ejected electron collides with another target metal inelastically and its total kinetic energy is utilized to raise the temperature of target metal. The mass of target metal is 10^{-3} kg and its specific heat is 160 J/kg/ºC. If 10^{18} electrons are ejected per second, then find the rate of raise of temperature (in ºC/s) of the metal [Assume there is no loss of energy of ejected electron by any other process, all the electron are reaching the target metal with max kinetic energy and take hc=12400 ev-Å] **MP0025**

3. A beam of light has three wavelengths 4144Å, 4972Å & 6216 Å with a total intensity of 3.6×10^{-3} W.m^{-2} equally distributed amongst the three wavelengths. The beam falls normally on an area 1.0 cm^2 of a clean metallic surface of work function 2.3 eV. Assume that there is no loss of light by reflection and that each energetically capable photon ejects one electron. Calculate the number of photoelectrons liberated in two seconds. **MP0026**

4. In a photo electric effect set-up, a point source of light of power 3.2×10^{-3} W emits mono energetic photons of energy 5.0 eV. The source is located at a distance of 0.8 m from the centre of a stationary metallic sphere of work function 3.0 eV & of radius 8.0×10^{-3}m . The efficiency of photo electrons emission is one for every 10^6 incident photons. Assume that the sphere is isolated and initially neutral, and that photo electrons are instantly swept away after emission.

(a) Calculate the number of photo electrons emitted per second.

(b) Find the ratio of the wavelength of incident light to the De - Broglie wave length of the fastest photo electrons emitted.

(c) It is observed that the photo electron emission stops at a certain time t after the light source is switched on. Why ?

(d) Evaluate the time t. **MP0027**

5. Two identical nonrelativistic particles move at right angles to each other, possessing De Broglie wavelengths, λ_1 & λ_2 . Find the De Broglie wavelength of each particle in the frame of their centre of mass. **MP0028**

6. Assume that the de-Broglie wave associated with an electron can form a standing wave between the atoms arranged in a one dimensional array with nodes at each of the atomic sites. It is found that one such standing wave is formed if the distance 'd' between the atoms of the array is 2 Å. A similar standing wave is again formed if 'd' is increased to 2.5 Å but not for any intermediate value of d. Find the energy of the electrons in electron volts and the least value of d for which the standing wave of the type described above can form. **MP0029**

7. A gas of identical hydrogen like atoms has some atoms in the lowest (ground) energy level A & some atoms in a particular upper (excited) energy level B & there are no atoms in any other energy level. The atoms of the gas make transition to a higher energy level by the absorbing monochromatic light of photon energy 2.55eV. Subsequently, the atoms emit radiation of only six different photon energies. Some of the emitted photons have energy 2.55 eV. Some have energy more and some have less than 2.55 eV.

(i) Find the principal quantum number of the initially excited level B.

(ii) Find the ionisation energy for the gas atoms.

(iii) Find the maximum and the minimum energies of the emitted photons.

MP0030

8. A monochromatic light source of frequency ν illuminates a metallic surface and ejects photoelectrons. The photoelectrons having maximum energy are just able to ionize the hydrogen atoms in ground state. When the whole experiment is repeated with an incident radiation of frequency $(5/6)\nu$, the photoelectrons so emitted are able to excite the hydrogen atom beam which then emits a radiation of wavelength of 1215 Å. Find the work function of the metal and the frequency ν. **MP0031**

9. A neutron of kinetic energy 65 eV collides inelastically with a singly ionized helium atom at rest. It is scattered at an angle of 90° with respect of its original direction.

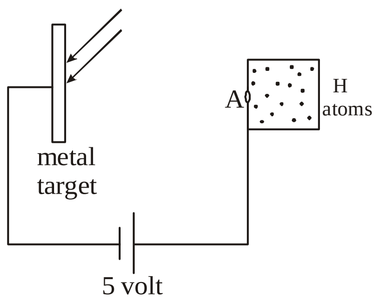
(Given : Mass of he atom = 4×(mass of neutron), ionization energy of H atom =13.6 eV)

(i) Find the allowed values of the energy of the neutron & that of the atom after collision.

(ii) If the atom gets de-excited subsequently by emitting radiation, find the frequencies of the emitted radiation. **MP0032**

10. A beam of ultraviolet light of wavelength 100 nm – 200 nm is passed through a box filled with hydrogen gas in ground state. The light coming out of the box is split into two beams 'A' and 'B'. A contains unabsorbed light from the incident light and B contains the emitted light by hydrogen atoms. The beam A is incident on the emitter in a photoelectric tube. The stopping potential in this case is 5 volts. Find the work function of the emitter. In the second case the beam B is incident on the same emitter. Find the stopping potential in this case. You can assume that the transition to higher energy states are not permitted from the excited states. Use hc = 12400 eVÅ. **MP0033**

11. Electromagnetic waves of wavelength 1242 Å are incident on a metal of work function 2eV. The target metal is connected to a 5 volt cell, as shown. The electrons pass through hole A into a gas of hydrogen atoms in their ground state. Find the number of spectral lines emitted when hydrogen atoms come back to their ground states after having been excited by the electrons. Assume all excitations in H-atoms from ground state only. (hc = 12420 eVÅ)



MP0034

12. A He^+ ion in ground state is fired towards a Hydrogen atom in ground state and at rest. What should be the minimum kinetic energy (in eV) of He^+ ion so that both single electron species may get excited. **MP0035**

13. Consider a universe in which the π-meson orbits around the nucleus instead of electron. Assuming a Bohr model for a π-meson of mass m_π and of the same charge as the electron is in a circular orbit of radius r about the nucleus with an orbital angular momentum $\frac{h}{2\pi}$. If the radius of a nucleus of atomic number Z is given by R = 1.6 × 10^{-15} $Z^{1/3}$ m. The total number of elements in this universe that can exist bis given as 'N'. Fill $\left[\frac{N-1}{12}\right]$ in OMR sheet. [Given $\frac{\varepsilon_0 h^2}{\pi m_e e^2} = 0.53Å$; $\frac{m_\pi}{m_e} = 265$; neglect any shielding effect for the havier atoms and assume non relativistic physics to be applicable and take $5^{1/4} \approx 1.5$] **MP0036**

14. The peak emission from a black body at a certain temperature occurs at a wavelength of 6000 Å. On increasing its temperature, the total radiation emitted is increased 16 times. These radiations are allowed to fall on a metal surface. Photoelectrons emitted by the peak radiation at higher temperature can be bought to rest by applying a potential equivalent to the excitation potential corresponding to the transition for the level n = 4 to n = 2 in the Bohr's hydrogen atom. The work function of the metal is given by $\frac{\alpha}{100}$ eV where α is the numerical constant. Find the value of α. [Take : hc = 12420 eV-Å]

MP0037

15. A neutron beam, in which each neutron has same kinetic energy, is passed through a sample of hydrogen like gas (but not hydrogen) in ground state. Due to collision of neutrons with the ions of the gas, ions are excited and then they emit photons. Six spectral lines are obtained in which one of the lines is of wavelength (6200/51) nm. What is the minimum possible value of kinetic energy of the neutrons for this to be possible. The mass of neutron and proton can be assumed to be nearly same. Find the answer in the form $25\alpha \times 10^{-2}$ eV and fill value of α. **MP0038**

16. Electrons in a hydrogen like atom (Z = 3) make transitions from the fourth excited state to the third excited state and from the third excited state to the second excited state. The resulting radiations are incident on a metal plate and eject photoelectrons. The stopping potential for photoelectrons ejected by shorter wavelength is 3.95 eV. Find the work function (in eV) of the metal plate. **MP0039**

17. A hydrogen atom at rest is in ground state. It is struck by a He^+ ion in first excited state. Assuming the collision to be head on and the mass of He^+ to be four times that of hydrogen atom, find the least value of kinetic energy of incoming particle which can excite both the particles to second excited state.

MP0040

18. In an X-ray tube the accelerating voltage is 20 KV. Two targets A and B are used one by one. For 'A' the wavelength of the K_α line is 62 pm. For 'B' the wavelength of the L_α line is 124 pm. The energy of the 'B' ion with vacancy in 'L' shell is 15.5 KeV higher than the atom of B.
[Take hc = 12400 eVÅ]
(i) Find λ_{min} in Å.
(ii) Can K_α – photon be emitted by 'A'? Explain with reason.
(iii) Can L – photons be emitted by 'B'? What is the minimum wavelength (in Å) of the characteristic X-ray that will be emitted by 'B'. **MP0041**

19. An X-rays tube is working at a potential difference of 38.08 kV. The potential difference is decreased to half its initial value. It is found that difference of the wavelength of K_α X-ray and the most energetic continuous X-rays becomes 1/4 times of the difference prior to the change of voltage. Assuming K_α line is present in both cases, find the atomic number of the target element. [Take Rch = 13.6 eV]

MP0042

EXERCISE (O-1)

SINGLE CORRECT TYPE QUESTIONS

Photoelectric Effect

1. **Statement 1** : Photoelectric effect establishes quantum nature of light.

and

Statement 2 : There is negligible time lag between photon collisions with the material and photoelectron emission irrespective of intensity of incident light. (Assume incident light is of frequency greater than threshold frequency of the material).

(A) Statement-1 is true, statement-2 is true and statement-2 is correct explanation for statement-1.

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

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true. **MP0043**

2. **Statement-1 :** Work function of aluminum is 4.2 eV. If two photons each of energy 2.5 eV strikes on a piece of aluminum, the photo electric emission does not occur

Statement-2 : In photo electric effect a single photon interacts with a single electron and electron is emitted only if energy of each incident photon is greater then the work function.

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

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

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

(D) Statement-1 is False, Statement-2 is True **MP0044**

3. A photocell is illuminated by a small bright source placed 1 m away. When the same source of light is place $\frac{1}{2}$ m away, the number of electrons emitted by photocathode would- **[AIEEE - 2005]**

(A) decrease by a factor of 4 (B) increase by a factor of 4

(C) decrease by a factor of 2 (D) increase by a factor of 2

MP0045

4. Two monochromatic light sources, A and B, emit the same number of photons per second. The wavelength of A is λ_A = 400 nm, and that of B is λ_B = 600 nm. The power radiated by source B is

(A) equal to that of source A

(B) less than that of source A

(C) greater than that of source A

(D) cannot be compared to that from source A using the available data.

MP0046

5. The energy flux of sunlight reaching the surface of the earth is 1.388×10^3 W/m^2. How many photons (nearly) per square metre are incident on the Earth per second? Assume that the photons in the sunlight have an average wavelength of 550 nm. **NCERT**

(A) 8×10^{21} (B) 4×10^{21} (C) 4×10^{38} (D) 8×10^{38}

MP0047

6. The threshold frequency for a certain metal is 3.3×10^{14} Hz. If light of frequency 8.2×10^{14} Hz is incident on the metal, the cutoff voltage for the photoelectric emission is. **NCERT**

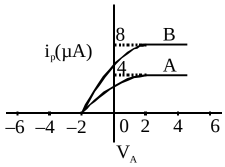
(A) 8 V (B) 6 V (C) 2 V (D) 4 **MP0048**

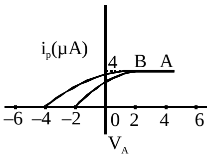
7. Light of frequency 7.21×10^{14} Hz is incident on a metal surface. Electrons with a maximum speed of 6.0×10^{5} m/s are ejected from the surface. The threshold frequency for photoemission of electrons is **NCERT**

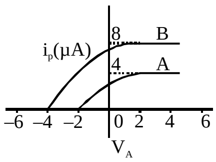
(A) 4.73×10^{14} Hz (B) 4.73×10^{10} Hz (C) 2.08×10^{10} Hz (D) None of these

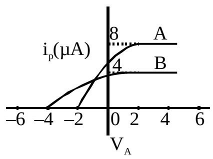
MP0049

8. In a photoelectric effect experiment, photons of energy 5 eV are incident on the photo-cathode of work function 3 eV. For photon intensity $I_A = 10^{15}$ $m^{-2}s^{-1}$, saturation current of 4.0 μA is obtained. Sketch of the variation of photocurrent i_p against the anode voltage V_a for photon intensity I_A (curve A) and $I_B = 2 \times 10^{15}$ m^{-2} s^{-1} (curve B) will be :

(A) 

(B) 

(C) 

(D) 

MP0050

9. **Statement-1 :** When ultraviolet light is incident on a photocell, its stopping potential is V_0 and the maximum kinetic energy of the photoelectrons is K_{max}. When the ultraviolet light is replaced by infrared light, both V_0 and K_{max} increase.

Statement-2 : Photoelectrons are emitted with speeds ranging from zero to a maximum value.

(A) Statement–1 is true, Statement–2 is false

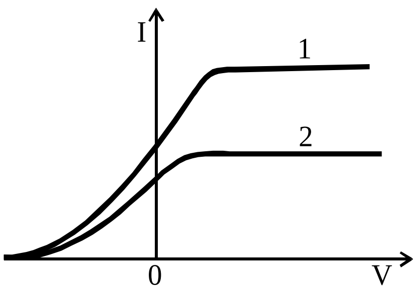
(B) Statement–1 is true, Statement–2 is true; Statement–2 is the correct explanation of Statement–1

(C) Statement–1 is true, Statement–2 is true; Statement–2 is not the correct explanation of Statement–1

(D) Statement–1 is false, Statement–2 is true

MP0051

10. A photocathode can be illuminated by the light from two sources, each of which emits monochromatic radiation. The sources are positioned at equal distances from the photocathode. The dependence of the photocurrent on the voltage between the cathode and the anode is depicted by curve 1 for one source and by curve 2 for the other. In what respect do these **sources** differ ?



(A) Highest frequency photon (B) Number of photons emmited per second

(C) Number of photoelectrons emmited per second

(D) None of these

MP0052

11. A radiation of energy E falls normally on a perfectly reflecting surface. The momentum transferred to the surface is- **[AIEEE - 2004]**

(A) E/c (B) 2E/c (C) Ec (D) E/c^2

MP0053

12. The threshold frequency for a metallic surface corresponds to an energy of 6.2 eV and the stopping potential for a radiation incident on this surface is 5V. The incident radiation lies in- **[AIEEE - 2006]**

(A) ultra-violet region (B) infra-red region (C) visible region (D) X-ray region

MP0054

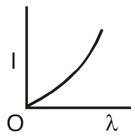
13. The time taken by a photoelectron to come out after the photon strikes is approximately-

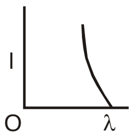
[AIEEE - 2006]

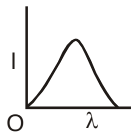
(A) 10^{-4} s (B) 10^{-10} s (C) 10^{-16} (D) 10^{-1} s

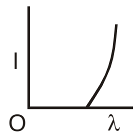
MP0055

14. The anode voltage of a photocell is kept fixed. The wavelength λ of the light falling on the cathode is gradually changed. The plate current I of the photocell varies as follows : **[AIEEE - 2006]**

(A) 

(B) 

(C) 

(D) 

MP0056

15. Photon of frequency ν has a momentum associated with it. If c is the velocity of light, the momentum is- **[AIEEE - 2007]**

(A) ν/c (B) $h\nu c$ (C) $h\nu/c^2$ (D) $h\nu/c$

MP0057

Wave Nature oF Matter

16. **Statement-1 :** If an electron has the same wavelength as a photon, they have the same energy.

Statement-2 : by debroglie hypothesis, $p = h/\lambda$ for both the electron and the photon.

(A) Statement-1 is true, statement-2 is true and statement-2 is correct explanation for statement-1.

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

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true.

MP0058

17. A particle of mass 4m at rest decays into two particles of masses m and 3m having non-zero velocities. The ratio of the de-Broglie wavelengths of the particles 1 and 2 is

(A) $\frac{1}{2}$ (B) $\frac{1}{4}$ (C) 2 (D) 1

MP0059

18. A free particle with initial kinetic energy E and de–broglie wavelength λ enters a region in which it has potential energy U. What is the particle's new de–Broglie wavelength?

(A) $\lambda(1-U/E)^{-1/2}$ (B) $\lambda(1-U/E)$ (C) $\lambda(1-E/U)^{-1}$ (D) $\lambda(1+U/E)^{1/2}$

MP0060

19. Proton, deutron and α particles are accelerated through the same potential difference. Then the ratio of their de-Broglie wavelength as

(A) $1:\sqrt{2}:1$ (B) $1:1:1$ (C) $1:2:2\sqrt{2}$ (D) $2\sqrt{2}:2:1$

MP0061

20. **Statement-1 :** An electron and a proton are accelerated through the same potential difference. The de-Broglie wavelength associated with the electron is longer.

Statement-2 : De-Broglie wavelength associated with a moving particle is $\lambda = \frac{h}{p}$ where, p is the linear momentum and both have same KE.

(A) Statement-1 is true, statement-2 is true and statement-2 is correct explanation for statement-1.

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

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true.

MP0062

21. An α-particle of energy 5 MeV is scattered through 180° by a fixed uranium nucleus. The distance of the closest approach is of the order of- **[AIEEE-2004]**

(A) 1 Å (B) 10^{-10} cm (C) 10^{-12} cm (D) 10^{-15} cm

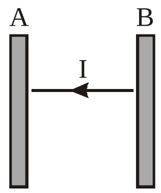
MP0063

22. After absorbing a slowly moving neutron of mass m_N (momentum ~0) a nucleus of mass M breaks into two nuclei of masses m_1 and $3m_1(4m_1 = M + m_N)$, respectively. If the de Broglie wavelength of the nucleus with mass m_1 is λ, then de-Broglie wavelength of the other nucleus will be:-

(A) 9λ (B) 3λ (C) $\frac{\lambda}{3}$ (D) λ

MP0064

23. A parallel beam of light of intensity I is incident normally on a plane surface A which absorbs 50% of the incident light. The reflected light falls on B which is perfect reflector, the light reflected by B is again partly reflected and partly absorbed and this process continues. For all absorption by A, asborption coefficient is 0.5. The pressure experienced by A due to light is :-



(A) $\frac{1.5\,I}{c}$ (B) $\frac{I}{c}$ (C) $\frac{3I}{2c}$ (D) $\frac{3I}{c}$

MP0065

24. **Statement-1 :** If the accelerating potential in an X-ray tube is increased, the wavelengths of the characteristic X-rays do not change. **[JEE 2007]**

because

Statement-2 : When an electron beam strikes the target in an X-ray tube, part of the kinetic energy is converted into X-ray energy

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

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

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

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

MP0066

25. Electrons with de-Broglie wavelength λ fall on the target in an X-ray tube. The cut-off wavelength of the emitted X-rays is **[JEE 2007]**

(A) $\lambda_0 = \dfrac{2mc\lambda^2}{h}$ (B) $\lambda_0 = \dfrac{2h}{mc}$ (C) $\lambda_0 = \dfrac{2m^2c^2\lambda^3}{h^2}$ (D) $\lambda_0 = \lambda$

MP0067

Bohr's Theory

26. The de-Broglie wavelength of an electron in the first Bohr orbit is

(A) equal to the circumference of first orbit (B) equal to $\dfrac{1}{2}$ × (circumference of first orbit)

(C) equal to $\dfrac{1}{4}$ × (circumference of first orbit) (D) equal to $\dfrac{3}{4}$ × (circumference of first orbit)

MP0068

27. **Statement–1** : When light is passed through a sample of hydrogen atoms in ground state, then wavelengths of absorption lines are same as wavelengths of lines of Lyman series in emission spectrum.

and

Statement–2 : In ground state hydrogen atom will absorb only those radiation which will excite to higher energy level.

(A) Statement-1 is true, statement-2 is true and statement-2 is correct explanation for statement-1.

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

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true.

MP0069

28. **Statement-1 :** In a laboratory experiment, on emission from atomic hydrogen in a discharge tube, only a small number of lines are observed whereas a large number of lines are present in the hydrogen spectrum of a star.

Statement-2 : The temperature of discharge tube is much smaller than that of the star.

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

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

Statement-1

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

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

MP0070

29. If the binding energy of the electron in a hydrogen atom is 13.6 eV, the energy required to remove the electron from the first excited state of Li^{2+} is- **[AIEEE - 2003]**

(A) 30.6 eV (B) 13.6 eV (C) 3.4 eV (D) 122.4 eV

MP0071

30. A neutron having kinetic energy 13.6 eV collides with a hydrogen atom in ground state at rest. Assume that the mass of neutron and hydrogen atoms are same and the neutron does not leave its line of motion. Then which of the following is the possible KE of the neutron after the collision?

(A) zero (B) 3.4 eV (C) 1.5 eV (D) 6.8 eV.

MP0072

31. In the spectrum of single ionised helium, the wavelength of a line observed is almost the same as the first line of Balmer series of hydrogen. It is due to transition of electron from

(A) $n_1 = 6$ to $n_2 = 4$ (B) $n_1 = 5$ to $n_2 = 3$ (C) $n_1 = 4$ to $n_2 = 2$ (D) $n_1 = 3$ to $n_2 = 2$

MP0073

32. Light coming from a discharge tube filled with hydrogen falls on the cathode of the photoelectric cell. The work function of the surface of cathode is 4eV. Which one of the following values of the anode voltage (in Volts) with respect to the cathode will likely to make the photo current zero.

(A) – 4 (B) – 6 (C) – 8 (D) – 10

MP0074

33. According to Bohr model, magnetic field at the centre (at the nucleus) of a hydrogen atom due to the motion of the electron in n^{th} orbit is proportional to

(A) $1/n^3$ (B) $1/n^5$ (C) n^5 (D) n^3

MP0075

34. A photon of 10.2 eV energy collides with a hydrogen atom in ground state inelastically. After few microseconds one more photon of energy 15 eV collides with the same hydrogen atom.Then what can be detected by a suitable detector. **[JEE' 2005 (Scr)]**

(A) one photon of 10.2 eV and an electron of energy 1.4 eV

(B) 2 photons of energy 10.2 eV

(C) 2 photons of energy 3.4 eV

(D) 1 photon of 3.4 eV and one electron of 1.4 eV

MP0076

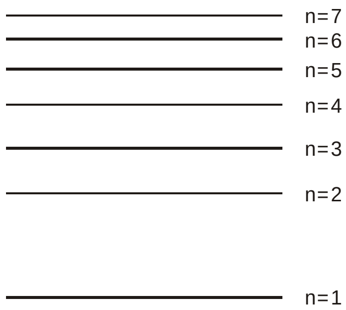
35. Two hydrogen atoms are in excited state with electrons residing in n = 2. First one is moving towards left and emits a photon of energy E_1 towards right. Second one is moving towards left with same speed and emits a photon of energy E_2 towards left. Taking recoil of nucleus into account during emission process

(A) $E_1 > E_2$ (B) $E_1 < E_2$

(C) $E_1 = E_2$ (D) information insufficient

MP0077

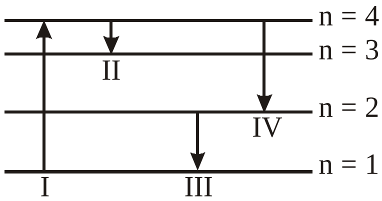
36. The maximum number of emission lines for atomic hydrogen that you would expect to see with naked eye if the only electronic levels involved are those shown in the figure, is



(A) 6 (B) 5 (C) 21 (D) ∞

MP0078

37. The diagram shows the energy levels for an electron in a certain atom. Which transition shown represents the emission of a photon with maximum wavelength?



(A) III (B) IV (C) I (D) II

MP0079

38. The largest wavelength in the ultraviolet region of the hydrogen spectrum is 122 nm. The smallest wavelength in the infrared region of the hydrogen spectrum (to the nearest integer) is

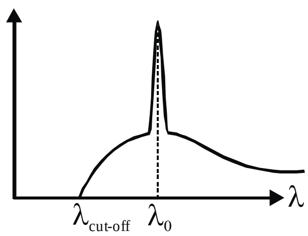
[JEE 2007]

(A) 802 nm (B) 823 nm (C) 1882 nm (D) 1648 nm

MP0080

X-Rays

39. **Assertion (A):** Variation of intensity of X-rays is plotted against λ. On increasing the accelerating potential, $(\lambda_0 - \lambda_{cut\text{-}off})$ increases.



Reasoning (R): $\lambda_{cut\text{-}off}$ will decrease but λ_0 will be same, as wavelength of characteristic X-rays is independent of the accelerating potential.

Choose the correct statement from the following.

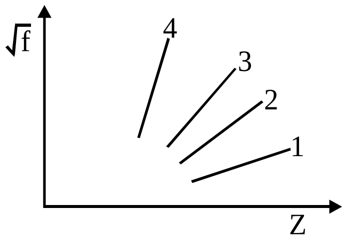
(A) A is correct and R is the correct explanation of A.

(B) Both A and R are correct but R is not the correct explanation of A.
(C) A is correct but R is wrong.
(D) Both A and R are wrong. **MP0081**

40. An X-ray tube is run at 50 kV. The current flowing in it is 20mA . The power of the tube is :
(A) 1000 W (B) 200 W (C) 20000 W (D) 20 W
MP0082

41. Choose the **INCORRECT** statement.
(A) Cut-off wavelength of X-rays is independent of filament voltage.
(B) Presence of K_α-line in X-ray spectrum means that L-series will also be present.
(C) Increase in filament current increases intensity of X-ray.
(D) Presence of L-series in X-ray spectrum means that K-series will also be present.
MP0083

42. The given graph shows the variation of $\sqrt{f}$ vs Z for characteristics X-rays. Lines 1, 2, 3, 4 shown in the graph corresponds to any one of k_α, k_β, L_α, L_β. Then L_β is represent by :-



(A) line 1 (B) line 2 (C) line 3 (D) line 4
MP0084

43. The X-ray beam coming from an X-ray tube will be
(A) monochromatic
(B) having all wavelengths smaller than a certain maximum wavelength
(C) having all wavelengths larger than a certain minimum wavelength
(D) having all wavelengths lying between a minimum and a maximum wavelength
MP0085

44. E_1 is energy of k_α photon of aluminium, E_2 is energy of k_β photon of aluminium and E_3 is energy of k_α photon from sodium, then the correct order of energies is given
(A) $E_1 > E_2 > E_3$ (B) $E_3 > E_2 > E_1$ (C) $E_3 > E_1 > E_2$ (D) $E_2 > E_1 > E_3$
MP0086

45. The K,L and M energy levels of platinum lie roughly at 78, 12 and 3 keV respectively. The ratio of wavelength of K_α line to that of K_β line in X-ray spectrum is-

(A) $\frac{22}{3}$ (B) $\frac{3}{22}$ (C) $\frac{22}{25}$ (D) $\frac{25}{22}$

MP0087

46. What is the essential distinction between X–rays and γ–rays

(A) γ–rays have shorter wavelength than X–rays

(B) γ–rays are extraterrestrial, X–rays are man–made

(C) γ–rays have less penetrating power than X–rays

(D) γ–rays originate from within an atomic nucleus, X–rays from outside an atomic nucleus.

MP0088

47. Mosley law relates :

(A) Frequency of emitted X-ray with applied voltage

(B) Wavelength and intensity of X-ray.

(C) Frequency of emitted X-ray with atomic number

(D) Wavelength and angle of scattering.

MP0089

48. The intensity of gamma radiation from a given source is I. On passing through 36 mm of lead, it is reduced to I/8. The thickness of lead, which will reduce the intensity to I/2 will be- **[AIEEE-2005]**

(A) 6 mm (B) 9 mm (C) 18 mm (D) 12 mm

MP0090

49. The wavelength of K_α X-ray of an element having atomic number Z = 11 is λ . The wavelength of K_α X-ray of another element of atomic number Z' is 4λ. Then Z' is **[JEE' 2005 (Scr)]**

(A) 11 (B) 44 (C) 6 (D) 4

MP0091

50. Characteristic X-ray

(A) Have only discrete wavelength which are characteristic of the target.

(B) Have all the possible wavelength.

(C) Are characteristic of speed of projectile electrons.

(D) None

MP0092

51. Which of the following transitions in hydrogen atoms emit photons of highest frequency ?

[AIEEE - 2007]

(A) n = 2 to n = 6 (B) n = 6 to n = 2 (C) n = 2 to n = 1 (D) n = 1 to n = 2

MP0093

MULTIPLE CORRECT TYPE QUESTIONS

52. Photoelectric effect supports quantum nature of light because

(A) there is minimum frequency of light below which no photoelectrons are emitted

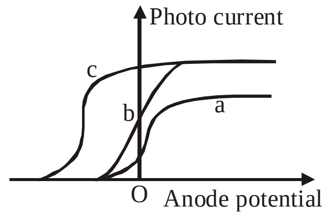
(B) the maximum kinetic energy of photo-electrons depends only on the frequency of light and not on its intensity

(C) even when the metal surface is faintly illuminated, the photoelectrons leave the surface immediately

(D) electric charge of photo-electrons is quantized

MP0094

53. The figure shows the variation of photo current with anode potential for a photosensitive surface for three different radiations. Let I_a, I_b and I_c be the intensities and f_a, f_b and f_c be the frequencies for the curves a, b and c respectively. Choose correct options



(A) $f_a = f_b$ (B) $I_a < I_b$ (C) $f_c < f_b$ (D) $I_c > I_b$

MP0095

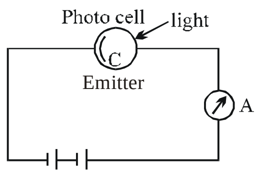
54. In photoelectric effect, stopping potential depends on
(A) frequency of the incident light
(B) intensity of the incident light by varies source distance
(C) emitter's properties
(D) frequency and intensity of the incident light

MP0096

55. Which of the following phenomena can be explained only on the basis of quantum theory of light?
(A) Energy spectrum of black body radiation (B) Atomic spectra
(C) Photoelectric effect (D) Doppler effect

MP0097

56. The figure shows a photo cell circuit. The cathode of the photo cell is illuminated by a monochromatic light. If the intensity is kept constant and the frequency of the incident light is increased, then the



(A) photo electric current in the circuit increases
(B) photo electric current in the circuit decreases
(C) maximum kinetic energy of the photo electrons increases
(D) photo electric current in the circuit can be reduced to zero, when the polarity of the terminals is reversed

MP0098

57. In a photoelectric effect, electrons are emitted
(A) at a rate that is proportional to the square of the amplitude of the incident radiation.
(B) with a maximum velocity proportional to the frequency of the incident radiation.
(C) at a rate that is independent of the emitter.
(D) only if the frequency of the incident radiation is above a certain threshold value
(E) only if the temperature of the emitter is high

MP0099

58. A small plate of area 1 cm^2 is placed at a distance of $\frac{1}{\sqrt{\pi}}$ m from an isotropic point source emitting light of frequency $\frac{1}{6.63}\times 10^{14}$ Hz, at a power of 2.00 mW. Assume the plate to be normal to the incident photons. [where h = 6.63×10^{-34} J-s]. Select **CORRECT** alternative(s)
(A) Energy possessed by each photon is 10^{-20} J
(B) Photon emission rate is 2×10^{17} s^{-1}
(C) The fraction of area of beam intercepted by the plate is $\frac{1}{4}\times 10^{-4}$
(D) The rate of photons striking the plate is 5×10^{12} per second.

MP0100

59. A metallic sphere of radius r remote from all other bodies is irradiated with a radiation of wavelength λ which is capable of causing photoelectric effect.

(A) the maximum potential gained by the sphere will be independent of its radius

(B) the net positive charge appearing on the sphere after a long time will depend on the radius of the sphere

(C) the maximum kinetic energy of the electrons emanating from the sphere will keep on declining with time

(D) the kinetic energy of the most energetic electrons emanating from the sphere initially will be independent of the radius of the sphere.

MP0101

60. Two electrons are moving with the same speed v. One electron enters a region of uniform electric field while the other enters a region of uniform magnetic field, then after sometime if the de–Broglie wavelengths of the two are λ_1 and λ_2, then select the possible option(s) :-

(A) $\lambda_1 = \lambda_2$ (B) $\lambda_1 > \lambda_2$

(C) $\lambda_1 < \lambda_2$ (D) $\lambda_1 > \lambda_2$ or $\lambda_1 < \lambda_2$

MP0102

61. A particle moves in a closed orbit around the origin, due to a central force which is directed towards the origin. The de Broglie wavelength of the particle varies cyclically between two values λ_1, λ_2 with $\lambda_1 > \lambda_2$. Which of the following statements is/are true ?

(A) The particle could be moving in a circular orbit with origin as centre

(B) The particle could be moving in an elliptic orbit with origin as its focus.

(C) When the de Broglie wave length is λ_1, the particle is nearer the origin than when its value is λ_2.

(D) When the de Broglie wavelength is λ_2, the particle is nearer the origin than when its value is λ_1.

MP0103

62. According to Bohr's theory of hydrogen atom, for the electron in the n^th^ permissible orbit,

(A) linear momentum $\propto \frac{1}{n}$

(B) radius of orbit $\propto$ n

(C) kinetic energy $\propto \frac{1}{n^2}$

(D) angular momentum $\propto$ n

MP0104

63. The magnitude of angular momentum, orbit radius and frequency of an electron in hydrogen atom corresponding to the quantum number n are L, r and f respectively, then according to Bohr's theory of hydrogen atom.

(A) frL is constant for all orbits (B) Lf $\propto \frac{1}{n^2}$

(C) fr $\propto \frac{1}{n}$ (D) Lr $\propto \frac{1}{n^3}$

MP0105

64. A particular hydrogen like atom has its ground state binding "energy 122.4eV. Its is in ground state. Then:

(A) Its atomic number is 3

(B) An electron of 90eV can excite it.

(C) An electron of kinetic energy nearly 91.8eV can be brought to almost rest by this atom.

(D) An electron of kinetic energy 2.6eV may emerge from the atom when electron of kinetic energy 125eV collides with this atom.

MP0106

65. A beam ofultraviolet light of all wavelengths passes through hydrogen gas at room temperature, in the x-direction. Assume that all photons emitted due to electron transition inside the gas emerge in the y-direction. Let A and B denote the lights emerging from the gas in the x and y directions respectively.

(A) Some of the incident wavelengths will be absent in A.

(B) Only those wavelengths will be present in B which are absent in A.

(C) B will contain some visible light.

(D) B will contain some infrared light.

MP0107

66. In the hydrogen atom, if the reference level of potential energy is assumed to be zero at the ground state level. Choose the incorrect statement.

(A) The total energy of the shell increases with increase in the value of n

(B) The total energy of the shell decrease with increase in the value of n.

(C) The difference in total energy of any two shells remains the same.

(D) The total energy at the ground state becomes 13.6 eV.

MP0108

67. A neutron collides head-on with a stationary hydrogen atom in ground state. Which of the following statements are correct (Assume that the hydrogen atom and neutron has same mass) :

(A) If kinetic energy of the neutron is less than 20.4 eV collision must be elastic.

(B) If kinetic energy of the neutron is less than 20.4 eV collision may be inelastic.

(C) Inelastic collision may be take place only when initial kinetic energy of neutron is greater than 20.4 eV.

(D) Perfectly inelastic collision can not take place.

MP0109

68. A free hydrogen atom in ground state is at rest. A neutron of kinetic energy 'K' collides with the hydrogen atom. After collision hydrogen atom emits two photons in succession one of which has energy 2.55 eV. (Assume that the hydrogen atom and neutron has same mass)

(A) minimum value of 'K' is 25.5 eV.

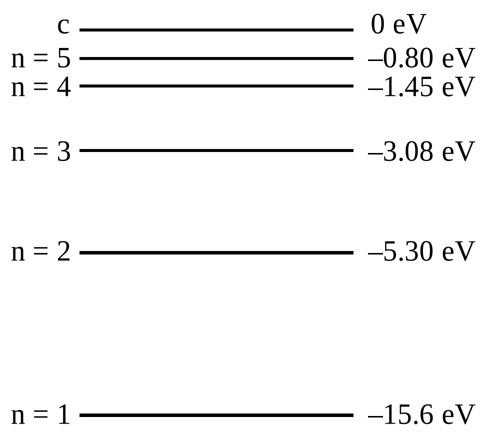
(B) minimum value of 'K' is 12.75 eV

(C) the other photon has energy 10.2 eV if K is minium.

(D) the upper energy level is of excitation energy 12.75 eV.

MP0110

69. The energy levels of a hypothetical one electron atom are shown in the figure



(A) The ionization potential of this atom is 15.6 V

(B) The short wavelength limit of the series terminating at n = 2 is 2339 Å

(C) The excitation potential for the state n = 3 is 12.52 V

(D) Wave number of the photon emitted for the transition n = 3 to n = 1 is 1.009×10^7 m^{-1}

MP0111

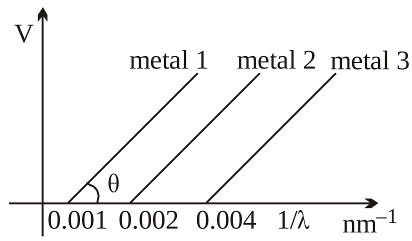
70. Suppose frequency of emitted photon is f_0 when electron of a stationary hydrogen atom jumps from a higher state m to a lower state n. If the atom is moving with a velocity v (<< c) and emits a photon of frequency f during the same transition, then which of the following statements are possible :-

(A) f may be equal to f_0 (B) f may be greater than f_0

(C) f may be less than f_0 (D) f cannot be equal to f_0

MP0112

71. The graph between 1/λ and stopping potential (V) of three metals having work functions ϕ_1, ϕ_2 and ϕ_3 in an experiment of photo-electric effect is plotted as shown in the figure. Which of the following statement(s) is/are correct? [Here λ is the wavelength of the incident ray]. **[JEE 2006]**



(A) Ratio of work functions $\phi_1 : \phi_2 : \phi_3 = 1 : 2 : 4$

(B) Ratio of work functions $\phi_1 : \phi_2 : \phi_3 = 4 : 2 : 1$

(C) tan θ is directly proportional to hc/e, where h is Planck's constant and c is the speed of light

(D) The violet colour light can eject photoelectrons from metals 2 and 3.

MP0113

MATRIX MATCH TYPE QUESTION

72. Some quantities related to the photoelectric effect are mentioned under Column I and Column II. Match each quantity in Column I with the corresponding quantities in Column II on which it depends

	Column-I		**Column-II**
(A)	Saturation current	(P)	Frequency of light
(B)	Stopping potential	(Q)	Work function
(C)	de-Broglie wavelength of photoelectron	(R)	Area of photosensitive plate
(D)	Force due to radiation falling on the photo–plate.	(S)	Intensity of light (at constant frequency)
		(T)	None of these

MP0114

73. When we write expression for energy of electron in n^{th} orbit of helium ion (He^+) we take zero potential energy for $n = \infty$, but the potential energy depends on reference. If we take total energy of atom for n = 1 orbit as zero then

	Column–I		**Column–II**
(A)	Total energy of electron in n = 2	(P)	54.4 eV
(B)	Ionization energy from ground state	(Q)	40.8 eV
(C)	Energy required to exit electron from n = 1 to n = 2	(R)	depends on reference level
(D)	Negative of potential energy of electron in n = 1	(S)	independent of reference level.
		(T)	70.3 eV

MP0115

74. In each situation of column–I a physical quantity related to orbiting electron in a hydrogen like atom is given. The terms 'Z' and 'n' given in column–II have usual meaning in Bohr's theory. Match the quantities in column–I with the terms they depend on in column–II :-

	Column-I		**Column-II**
(A)	Frequency of orbiting electron	(P)	Is directly proportional to Z^2
(B)	Angular momentum of orbiting electron	(Q)	Is directly proportional to n
(C)	Magnetic moment of orbiting electron	(R)	Is inversely proportional to n^3
(D)	The average current due to orbiting of electron	(S)	Is independent of Z
		(T)	None of these

MP0116

5. Match the entries of column–I with the entries of column–II :-

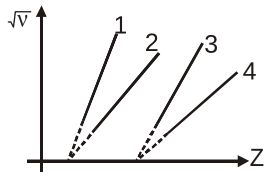
	Column-I		**Column-II**
(I)	Characteristic X-ray	(P)	Inverse process of photoelectric effect
(II)	Photoelectric effect	(Q)	Emission of electrons
(III)	Thermo-ionic emission	(R)	Moseley's law
(IV)	Continuous X-ray	(S)	Emission of radiations

Then choose the correct matching.

(A) (i) $\rightarrow$(RS) ; (ii) $\rightarrow$ (RS) ; (iii) $\rightarrow$(S) ; (iv) $\rightarrow$(PS)
(B) (i) $\rightarrow$(RS) ; (ii) $\rightarrow$ (Q) ; (iii) $\rightarrow$(Q) ; (iv) $\rightarrow$(PS)
(C) (i) $\rightarrow$(RS) ; (ii) $\rightarrow$ (S) ; (iii) $\rightarrow$(S) ; (iv) $\rightarrow$(PRS)
(D) (i) $\rightarrow$(RS) ; (ii) $\rightarrow$ (Q) ; (iii) $\rightarrow$(Q) ; (iv) $\rightarrow$(PRS)

MP0117

76. $\sqrt{\nu}$ versus Z graph for characteristic X–rays is as shown in figure. Match the following (assume screening constant for K_α and K_β is same and for L_α & L_β is same) :-



	Column-I		**Column-II**
(A)	Line – 1	(P)	L_α
(B)	Line – 2	(Q)	L_β
(C)	Line – 3	(R)	K_α
(D)	Line – 4	(S)	K_β
		(T)	Both K_α and L_β

MP0118

EXERCISE (O-2)

SINGLE CORRECT TYPE QUESTIONS

1. The maximum kinetic energy of photo-electron liberated from the surface of lithium (work function = 2.35 eV) by electromagnetic radiation whose electric component varies with time as $E = a[1 + \cos(2\pi f_1 t)] \cos(2\pi f_2 t)$ where 'a' is a constant, $f_1 = 3.6 \times 10^{15}$ Hz and $f_2 = 1.2 \times 10^{15}$ Hz is [Take : $h = 6.6 \times 10^{-34}$ J-s]

(A) 2. 6 eV (B) 7.55 eV (C) 12.5 eV (D) 17.45 eV

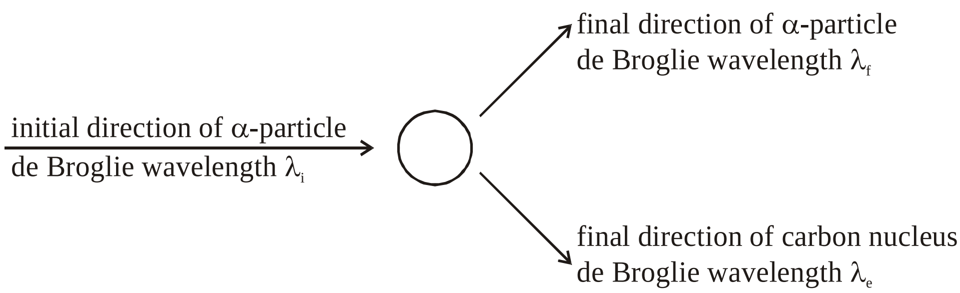
MP0119

2. A photocell in the saturation mode is irradiated by light of wavelength $\lambda = 6600$ Å. The corresponding spectral sensitivity of the cell is $s_\lambda = 4.8$ mA/W. Find the yield of photoelectrons, i.e. the number of photoelectrons produced by each incident photon. [Take : $h = 6.6 \times 10^{-34}$ J-s]

(A) 9×10^{-2} (B) 9×10^{-4} (C) 9×10^{-3} (D) 9

MP0120

3. An α-particle having a de Broglie wavelength λ_i collides with a stationary carbon nucleus. The α-particle moves off in a different direction as shown below.



After the collision, the de Broglie wavelength of the α-particle and the carbon nucleus are λ_f and λ_e respectively. Which of the following relations about de Broglie wavelength is correct ?

(A) $\lambda_i < \lambda_f$ (B) $\lambda_i > \lambda_f$ (C) $\lambda_f = \lambda_e$ (D) $\lambda_i = \lambda_e$

MP0121

4. Choose the correct statement(s) for hydrogen and deuterium atoms (considering motion of nucleus)

(A) The radius of first Bohr orbit of deuterium is less than that of hydrogen

(B) The speed of electron in the first Bohr orbit of deuterium is more than that of hydrogen.

(C) The wavelength of first Balmer line of deuterium is more than that of hydrogen

(D) The angular momentum of electron in the first Bohr orbit of deuterium is more than that of hydrogen.

MP0122

5. Apply Bohr's atomic model to a lithium atom. Assuming that its two K-shell electrons are too close to nucleus such that nucleus and K-shell electron act as a nucleus of effective positive charge equivalent to electron. The ionization energy of its outermost electron is:-

(A) 30.6 eV (B) 3.4 eV (C) 32.4 eV (D) 13.6 eV

MP0123

6. The attractive potential for an atom is given by $v = v_0\, ln\left(r/r_0\right)$, v_0 and r_0 are constant and r is the radius of the orbit. The radius r of the n^{th} Bohr's orbit depends upon principal quantum number n as:

[JEE' 2003 (Scr)]

(A) $r \propto n$ (B) $r \propto 1/n^2$ (C) $r \propto n^2$ (D) $r \propto 1/n$

MP0124

7. A force of attraction between the positively charged nucleus and the negatively charged electron in the hydrogen atom is given by $F = \frac{ke^2}{r^2}$ where k is the constant. The electron, initially moving in a circle of radius R_1 about the nucleus, jumps suddenly into a circular orbit of radius R_2. The total energy of the atom decreased in this process is :-

(A) $ke^2\left[\frac{1}{R_1}+\frac{1}{R_2}\right]$ (B) $\frac{ke^2}{2}\left[\frac{1}{R_2}-\frac{1}{R_1}\right]$ (C) $ke^2\left[\frac{R_1R_2}{R_2-R_1}\right]$ (D) $ke^2\left[\frac{R_1R_2}{R_1+R_2}\right]$

MP0125

8. A stationary hydrogen atom of mass M emits a photon corresponding to the longest wavelength of Balmer series. The recoil velocity acquired by the atom is (R = Rydberg constant and h = plank's constant)

(A) $\frac{Rh}{M}$ (B) $\frac{Rh}{4M}$ (C) $\frac{3}{4}\frac{Rh}{M}$ (D) $\frac{5}{36}\frac{Rh}{M}$

MP0126

9. Let the potential energy of a hydrogen atom in the ground state be zero. Then its energy in the first excited state will be :

(A) 10.2eV (B) 13.6eV (C) 23.8eV (D) 27.2 eV

MP0127

10. Hydrogen atoms in ground state are excited by monochromatic radiation of wavelength 975 Å. The number of liens in the resulting spectrum will be :

(A) 3 (B) 4 (C) 6 (D) 10

MP0128

11. The relation between λ_1 : wavelength of series limit of lyman λ_2 : the wavelength of the series limit of Balmer series and λ_3 : the wavelength of first line of lyman series is

(A) $\lambda_1 = \lambda_2 + \lambda_3$ (B) $\lambda_3 = \lambda_1 + \lambda_2$ (C) $\lambda_2 = \lambda_3 - \lambda_1$ (D) none

MP0129

12. A hydrogen like gas atoms absorb radiations of wavelength λ_0 and consequently emit radiations of 6 difference wavelengths of which, three wavelengths are shorter than λ_0. Choose the correct alternative(s).

(A) The final excited state of the atoms is n = 3.

(B) The final excited state of the atoms is n = 4.

(C) The initial state of the atoms is n =1.

(D) The initial state of the atoms is n =3.

MP0130

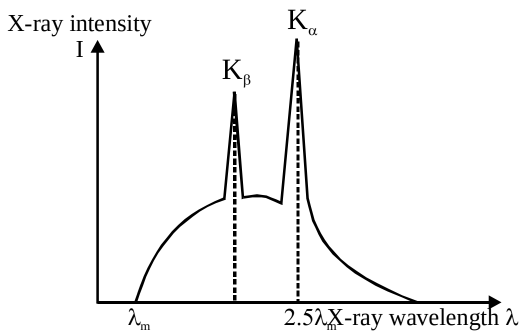
13. According to the Bohr theory of the hydrogen atom, electron starting in the 4th energy level and eventually ending in the ground state could produce a total of how many lines in the hydrogen spectra?

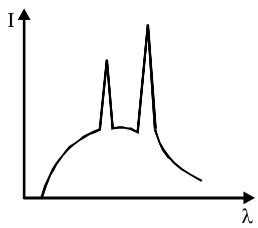
(A) 7 (B) 6 (C) 5 (D) 4

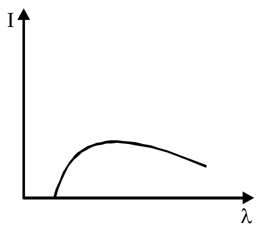
(E) 3

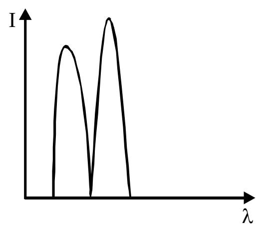
MP0131

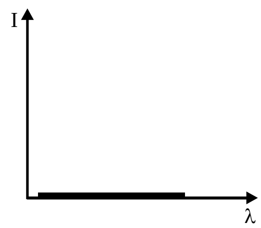
14. When an electron accelerated by potential difference U is bombarded on a specific metal the emitted X-ray spectrum obtained is shown in adjoining graph. If the potential difference is reduced to U/3, the correct spectrum is :-



(A)


(B)


(C)


(D)


MP0132

15. In an X-ray experiment target is made up of copper (Z = 29) having some impurity. The K_α line of copper have wavelength λ_0. It was observed that another K_α line due to impurity have wavelength $\frac{784}{625}\lambda_0$. The atomic number of the impurity element is

(A) 22 (B) 23 (C) 24 (D) 26

MP0133

MULTIPLE CORRECT TYPE QUESTIONS

16. In a photoelectric effect experiment, if f is the frequency of radiations incident on the metal surface and I is the intensity of the incident radiations, then choose the correct statement(s).

(A) If f is increased keeping I and work function constant then maximum kinetic energy of photoelectron increases.

(B) If distance between cathode and anode is increased stopping potential increases

(C) If I is increased keeping f and work function constant then stopping potential remains same and saturation current increases.

(D) Work function is decreased keeping f and I constant then stopping potential increases

MP0134

17. When a monochromatic point-source of light is at a distance of 0.2 m from a small photoelectric cell, the stopping potential and the saturation current are respectively 0.6 volt and 18.0 mA. If the same source is placed 0.6 m away from the photoelectric cell, then :-

(A) The stopping potential will be 0.2 volt
(B) The stopping potential will be 1.8 volt
(C) The saturation current will be 6.0 mA
(D) The saturation current will be 2.0 mA

MP0135

18. The collector of the photocell (in photoelectric experiment) is made of tungsten while the emitter is of Platinum having work function of 10 eV. Monochromatic radiation of wavelength 124 Å & power 100 watt is incident on emitter which emits photo electrons with a quantum efficiency of 1%. The accelerating voltage across the photocell is of 10,000 volts (Use : hc = 12400eV Å)

(A) The power supplied by the accelerating voltage source is 100 watt

(B) The minimum wavelength of radiation coming from the tungsten target (collector) is 1.23 Å

(C) The power supplied by the accelerating voltage source is 10 watt

(D) The minimum wavelength of radiation coming from the tungsten target (collector) is 2.23 Å

MP0136

19. Light of wavelength λ_1 & λ_2 are falling on two metal surface A & B. For wavelength λ_1 electron ejected from both the surfaces and for wavelength λ_2 electron ejected from only surface B. On the basis of these facts which one of the following is a false statement

(A) more energy is required for ejection of electron from metal 'A'

(B) $\lambda_1 > \lambda_2$

(C) threshold wavelength for A is greater than B

(D) energy of electron ejected from metal A will be greater than electron ejected from metal B for wavelength λ

MP0137

20. The accelerating potential (V) applied between a photocathode and the respective anode is such that the fastest photoelectron can fly only one fourth of the distance between the cathode and the anode. If the distance between photocathode and anode is reduced to $(1/4)^{th}$ of the original value while maintaining the accelerating potential constant, then

(A) The fastest electron will reach the anode

(B) The fastest electron will reach upto one fourth of the new distance between the cathode and the anode

(C) Kinetic energy of the fastest photoelectron emitted from photocathode will not change due to change in plate separation (keeping V constant)

(D) Kinetic energy of the fastest photoelectron will increase due to decrease in plate separation (keeping V constant)

MP0138

21. For the electron in the n^{th} orbit of hydrogen atom. Under the assumption of the Bohr's atomic model choose the **CORRECT** option(s) (Here n is the principal quantum number) :-

(A) Frequency of the electron is inversely proportional to n^3

(B) The magnitude of potential energy of the electron in an orbit is greater than its kinetic energy

(C) Magnetic induction at the nucleus produced due to the motion of electron in the n^{th} orbit is proportional to n^5

(D) Magnetic moment produced due to the motion of electron in the n^{th} orbit is proportional to n

MP0139

22. Energy liberated in the de-excitation of hydrogen atom from 3^{rd} level to 1^{st} level falls on a photo-cathode. Later when the same photocathode is exposed to a spectrum of some unknown hydrogen like gas, excited to 2^{nd} energy level, it is found that the de-Broglie wavelength of the fastest photoelectrons, now ejected has decreased by a factor of 3. For this new gas, difference of energies of 2^{nd} Lyman line and 1^{st} Balmer line is found to be 3 times the ionization potential of the hydrogen atom. Select the correct statement(s) :

(A) The gas is lithium

(B) The gas is helium

(C) The work function of photocathode is 8.5 eV

(D) The work function of photocathode is 5.5 eV

MP0140

23. An electron of the kinetic energy 10eV collides with a hydrogen atom in 1st excited state. Assuming loss of kinetic energy in the collision to be quantized, the collision :

(A) may be perfectly inelastic
(B) may be inelastic
(C) may be elastic
(D) must be inelastic

MP0141

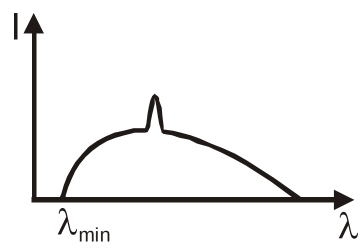
24. An X-ray tube has three main controls.

(i) the target material (its atomic number Z)

(ii) the filament current (I_f)

(iii) the accelerating voltage (V)

Figure shows a typical intensity distribution against wavelength.



Which of the following is **CORRECT**?

(A) The limit λ_{min} is proportional to V^{-1}

(B) The sharp peak shifts to the right as Z is increased

(C) The penetrating power of X-ray increases if V is increased

(D) The intensity everywhere increases if filament current I_f is increased

MP0142

COMPREHENSION TYPE QUESTIONS

Paragraph for Question 25 to 27

A mercury arc lamp provides 0.1 watt of ultra-violet radiation at a wavelength of λ = 2537 Å only. The photo tube (cathode of photo electric device) consists of potassium and has an effective area of 4 cm^2. The cathode is located at a distance of 1m from the radiation source. The work function for potassium is ϕ_0 = 2.22 eV.

25. According to classical theory, the radiation from arc lamp spreads out uniformly in space as spherical wave. What time of exposure to the radiation should be required for a potassium atom (radius 2Å) in the cathode to accumulate sufficient energy to eject a photo-electron ?

(A) 352 second (B) 176 second (C) 704 seconds (D) No time lag

MP0143

26. To what saturation current does the flux of photons at the cathode corresponds if the photo conversion efficiency is 5%.

(A) 32.5 nA (B) 10.15 nA (C) 65 nA (D) 3.25 nA

MP0143

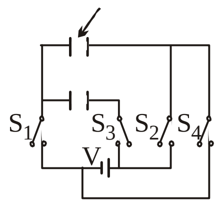
27. What is the cut off potential V_0 ?

(A) 26.9 V (B) 2.69 V (C) 1.35 V (D) 5.33 V

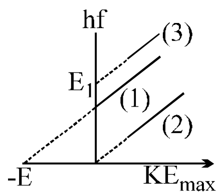
MP0143

Paragraph for question nos. 28 to 30

The circuit shown is placed in vacuum. Both the capacitors are identical and they have the same capacitance C. Light is incident on the left plate of the upper capacitor. When all the switches are open then the hf versus KE_{max} is shown by the straight line (A). In all the cases, we are measuring the KE_{max} when the electron reaches the opposite plate.



When only S_1 the switches and S_2 are closed, the graph becomes (B).
When only S_3 and S_4 are closed then the graph becomes (C).



28. What is the work function of the cathode?

(A) E (B) E_1 (C) E + E_1 (D) none of these

MP0144

29. What is the value of eV?

(A) E (B) E_1 (C) $E + E_1$ (D) none of these

MP0144

30. What is the value of E_1?

(A) 3E (B) 3E/2 (C) E/2 (D) none of these

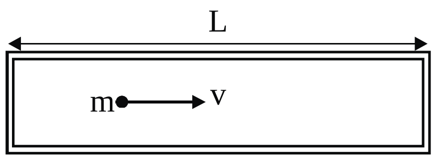
MP0144

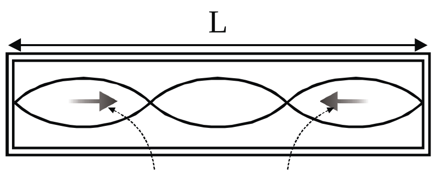
Paragraph for Question. 31 to 33

While conducting his doctoral research in theoretical physics and with no experimental evidence to go on, de Broglie reasoned by analogy with Einstein's equation E = hf and with some of the ideas of his theory of relativity. The details need not concern us, but they led de Broglie to postulate that if a material particle of momentum p = mv has a wave-like nature, then its wavelength must be given by

$\lambda = \dfrac{h}{p} = \dfrac{h}{mv}$ where h is Planck's constant. This is called the de-Broglie wavelength.

de-Broglie considered a matter wave to be a traveling wave. But suppose that a "particle" of matter is confined to a small region of space and cannot travel. How do the wave-like properties manifest themselves? This is the problem of "a particle in a box." Figure shows a particle of mass m moving in one dimension as it bounces back and forth with speed v between the ends of a box of length L. We'll call this a one-dimensional box; its width isn't relevant. A particle in a box creates a standing de Broglie wave as it reflects back and forth.





Matter waves travel in both directions.

31. What should be de-Broglie wavelength of confined particle in the box [here $n \in N$]

(A) $\dfrac{L}{2n}$ (B) $\dfrac{2L}{n}$ (C) $\dfrac{L}{n}$ (D) nL

MP0145

32. Confined particle's energy is given by

(A) $\dfrac{n^2h^2}{2mL^2}$ (B) $\dfrac{2n^2h^2}{mL^2}$ (C) $\dfrac{n^2h^2}{8mL^2}$ (D) $\dfrac{n^2h^2}{4mL^2}$

MP0145

33. Consider an oil drop from Millikan's oil drop experiment having diameter 1 μm confined between the plates separated by 10 μm. Density of oil is 900 kg/m^3. What is minimum energy of such an oil drop? [Given : h = 6.63×10^{-34} Js]

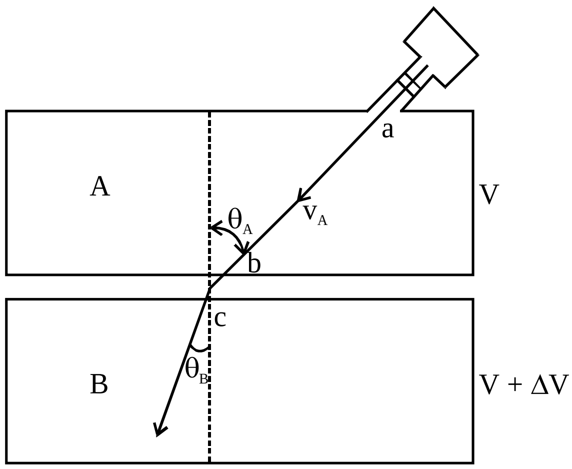
(A) 2.4×10^{-42} J (B) 1.2×10^{-42} J (C) 3.6×10^{-42} J (D) 4.8×10^{-42} J

MP0145

Paragraph for Question Nos. 34 to 36

Let a pencil of electrons from a suitable gun G enter through orifice in an enclosed metal box A, which has potential V relative to filament of the gun. Let these electrons emerge from A through orifice b and enter through c to another box B, which is maintained at a potential V + ΔV. The electric field between the two boxes changes the component of velocity of the electrons perpendicular to the adjacent surface, and the electrons enter B with a change in their direction of motion. Let v_A and v_B be the velocities of the electrons in A and B, respectively, and θ_A, θ_B the angles between these directions and the normal to the box faces at b and c. Since the electric field does not change the horizontal component of velocity,

$$v_A \sin\theta_A = v_B \sin\theta_B \qquad \frac{\sin\theta_A}{\sin\theta_B} = \frac{v_B}{v_A}$$



The "refraction" of a pencil of electrons

Now if we dealing with light waves undergoing refraction, or any other kind of wave, the relation would be

$$\frac{\sin\theta_A}{\sin\theta_B} = \mu = \frac{u_A}{u_B}$$

where μ is the relative refractive index of the two media and u_A, u_B are the corresponding velocities of light wave. Comparison of the last two equations gives the result $\frac{u_A}{u_B} = \frac{v_B}{v_A}$. We may conclude that if matter waves follow the electron along its path, the wave speed u is inversely proportional to the speed v of the electron, or $u = \frac{b}{v}$.

34. If we define the frequency of matter waves as $f = \frac{u}{\lambda}$, the

(A) Frequency of matter waves in medium A is more than that in medium B
(B) Frequency of matter waves in medium A is less than that in medium B
(C) Frequency of matter waves in medium A is same as that in medium B
(D) Cannot be predicted

MP0146

35. Suppose V_A = 20 volt and V_B = 15 volt. Choose the **CORRECT** statement :-
(A) The speed of electrons as well as speed of matter waves inside box B is more
(B) The speed of electrons as well as speed of matter waves inside box B is less
(C) The speed of electrons inside the box B is more, but speed of matter waves in box B is less
(D) The speed of electrons inside the box B is less, but speed of matter waves in box B is more

MP0146

36. The refractive index for matter waves can be defined as $\frac{c}{u}$ where c is some constant. So refractive index for matter waves

(A) is inversely proportional to λ
(B) is independent of λ
(C) is directly proportional of λ
(D) is proportional to $\sqrt{\lambda}$

MP0146

EXERCISE (JM)

1. Suppose an electron is attracted towards the origin by a force $\frac{k}{r}$ where 'k' is a cosntant and 'r' is the distance of the electron from the origin. By applying Bohr model to this sytem, the radius of the n^{th} orbital of the electron is found to be 'r_n' and the kinetic energy of the electron to be 'T_n'. Then which of the following is true? **[AIEEE - 2008]**

(1) $T_n \propto \frac{1}{n^2}, r_n \propto n^2$ (2) T_n independent of n, $r_n \propto n$

(3) $T_n \propto \frac{1}{n}, r_n \propto n$ (4) $T_n \propto \frac{1}{n}, r_n \propto n^2$ **MP0147**

2. The transistion from the state n = 4 to n = 3 in a hydrogen like atom results in ultraviolet radiation. Infrared radiation will be obtained in the transition from :- **[AIEEE - 2009]**

(1) $4 \rightarrow 2$ (2) $5 \rightarrow 4$ (3) $2 \rightarrow 1$ (4) $3 \rightarrow 2$

MP0148

3. The surface of a metal is illuminated with the light of 400 nm. The kinetic energy of the ejected photoelectrons was found to be 1.68 eV. The work function of the metal is : (hc = 1240 eV-nm)

[AIEEE - 2009]

(1) 1.51 eV (2) 1.68 eV (3) 3.09 eV (4) 1.41 eV

MP0149

Directions : Question number 4 contain Statement-1 and Statement-2. Of the four choices given after the statements, choose the one that best discribes the two statements.

4. Statement-1 : When ultraviolet light is incident on a photocell, its stopping potential is V_0 and the maximum kinetic energy of the photoelectrons is K_{max}. When the ultraviolet light is replaced by X-rays, both V_0 and K_{max} increase.

Statement-2 : Photoelectrons are emitted with speeds ranging from zero to a maximum value because of the range of frequencies present in the incident light. **[AIEEE - 2010]**

(1) Statement–1 is true, Statement–2 is false

(2) Statement–1 is true, Statement–2 is true; Statement–2 is the correct explanation of Statement–1

(3) Statement–1 is true, Statement–2 is true; Statement–2 is not the correct explanation of Statement–1

(4) Statement–1 is false, Statement–2 is true

MP0150

5. If a source of power 4kW produces 10^{20} photons/second, the radiation belongs to apart of the spectrum called :- **[AIEEE - 2010]**

(1) γ-rays (2) X-rays (3) ultraviolet rays (4) microwaves

MP0151

6. Energy required for the electron excitation in Li^{++} from the first to the third Bohr orbit is:-

[AIEEE-2011]

(1) 108.8 eV (2) 122.4 eV (3) 12.1 eV (4) 36.3 eV

MP0152

7. This question has Statememtn-1 and Statement-2. Of the four choices given after the statements, choose the one that best describes the two statements.

Statement–1 : A metallic surface is irradiated by a monochromatic light of frequency $v > v_0$ (the threshold frequency). The maximum kinetic energy and the stopping potential are K_{max} and V_0 respectively. If the frequency incident on the surface is doubled, both the K_{max} and V_0 are also boubled.

Statement-2 : The maximum kinetic energy and the stopping potential of photoelectrons emitted from a surface are linearly dependent on the frequency of incident light. **[AIEEE-2011]**

(1) Statement–1 is true, Statement–2 is true, Statement–2 is not the correct explanationof Statement–1

(2) Statement–1 is false, Statement–2 is true

(3) Statement–1 is true, Statement–2 is false

(4) Statement–1 is true, Statement–2 is true, Statement–2 is the correct explanation of Statement–1

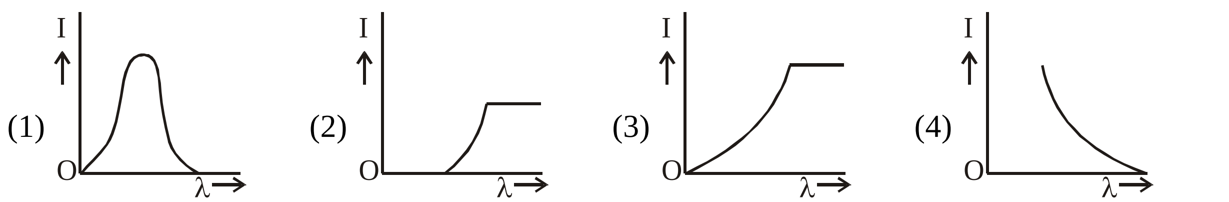
MP0153

8. Hydrogen atom is excited from ground state to another state with principal quantum number equal to 4. Then the number of spectral lines in the emission spectra will be :- **[AIEEE-2012]**

(1) 6 (2) 2 (3) 3 (4) 5

MP0154

9. The anode voltage of photocell is kept fixed. The wavelength λ of the light falling on the cathode is gradually changed. The plate current I of the photocell varies as follows : **[AIEEE-2013]**



MP0155

10. In a hydrogen like atom electron makes transition from an energy level with quantum number n to another with quantum number (n–1). If n >> 1, the frequency of radiation emitted is proportional to :

[JEE Main-2013]

(1) $\frac{1}{n}$ (2) $\frac{1}{n^2}$ (3) $\frac{1}{n^{3/2}}$ (4) $\frac{1}{n^3}$

MP0156

11. As an electron makes a transition from an excited state to the ground state of a hydrogen - like atom/ion : **[JEE Main-2015]**

(1) kinetic energy decreases, potential energy increases but total energy remains same

(2) kinetic energy and total energy decrease but potential energy increases

(3) its kinetic energy increases but potential energy and total energy decreases

(4) kinetic energy, potential energy and total energy decrease

MP0157

12. Match List-I (Fundament Experiment) with List-II (its conclusion) and select the correct option from the choices given below the list : **[JEE Main-2015]**

	List-I		**List-II**
(A)	Franck-Hertz Experiment.	(i)	Particle nature of light
(B)	Photo-electric experiment	(iii)	Discrete energy levels of atom
(C)	Davison-Germer Experiment	(iiii)	Wave nature of electroc
		(iv)	Structure of atom

(1) A-ii, B-i, C-iii (2) A-iv, B-iii, C-ii

(3) A-i, B-iv, C-iii (4) A-ii, B-iv, C-iii

MP0158

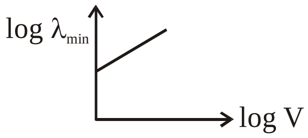
13. Radiation of wavelength λ, is incident on a photocell. The fastest emitted electron has speed v. If the wavelength of changed to $\frac{3\lambda}{4}$, the speed of the fastest emitted electron will be :-**[JEE Main-2016]**

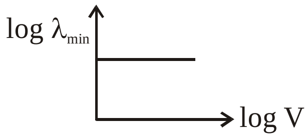
(1) $= v\left(\frac{3}{5}\right)^{1/2}$ (2) $> v\left(\frac{4}{3}\right)^{1/2}$ (3) $< v\left(\frac{4}{3}\right)^{1/2}$ (4) $= v\left(\frac{4}{3}\right)^{1/2}$

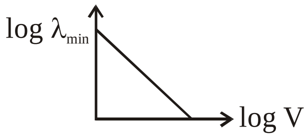
MP0159

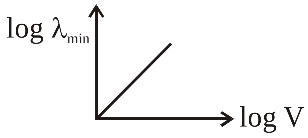
14. An electron beam is accelerated by a potential difference V to hit a metallic target to produce X-rays. It produces continuous as well as characteristic X-rays.If λ_{min} is the smallest possible wavelength of X-ray in the spectrum, the variation of log λ_{min} with log V is correctly represented in :

[JEE Main-2017]

(1)


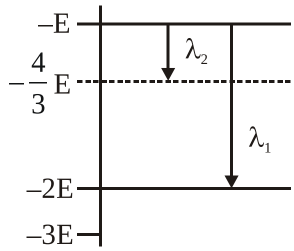
(2)


(3)


(4)


MP0160

15. Some energy levels of a molecule are shown in the figure. The ratio of the wavelengths $r = \lambda_1/\lambda_2$, is given by : **[JEE Main-2017]**



(1) $r = \frac{3}{4}$ (2) $r = \frac{1}{3}$ (3) $r = \frac{4}{3}$ (4) $r = \frac{2}{3}$

MP0161

16. A particle A of mass m and initial velocity v collides with a particle B of mass $\frac{m}{2}$ which is at rest. The collision is head on, and elastic. The ratio of the de–Broglie wavelengths λ_A to λ_B after the collision is: **[JEE Main-2017]**

(1) $\frac{\lambda_A}{\lambda_B} = \frac{2}{3}$ (2) $\frac{\lambda_A}{\lambda_B} = \frac{1}{2}$ (3) $\frac{\lambda_A}{\lambda_B} = \frac{1}{3}$ (4) $\frac{\lambda_A}{\lambda_B} = 2$

MP0162

17. If the series limit frequency of the Lyman series is v_L, then the series limit frequency of the Pfund series is : **[JEE Main-2018]**

(1) 16 v_L (2) $v_L/16$ (3) $v_L/25$ (4) 25 v_L

MP0163

EXERCISE (JA)

1. Which one of the following statements is **WRONG** in the context of X-rays generated from a X-ray tube ? **[JEE 2008]**

(A) Wavelength of characteristic X-rays decreases when the atomic number of the target increases

(B) Cut-off wavelength of the continuous X-rays depends on the atomic number of the target

(C) Intensity of the characteristic X-rays depends on the electrical power given to the X-rays tube

(D) Cut-off wavelength of the continuous X-rays depends on the energy of the electrons in the X-ray tube

MP0164

Paragraph for Question Nos. 2 to 4

In a mixture of H – He^+ gas (He^+ is singly ionized He atom), H atoms and He^+ ions are excited to their respective first excited states. Subsequently, H atoms transfer their total excitation energy to He^+ ions (by collisions). Assume that the Bohr model of atom is exactly valid. **[JEE 2008]**

2. The quantum number n of the state finally populated in He^+ ions is

(A) 2 (B) 3 (C) 4 (D) 5

MP0165

3. The wavelength of light emitted in the visible region by He^+ ions after collisions with H atoms is

(A) 6.5×10^{-7} m (B) 5.6×10^{-7} m (C) 4.8×10^{-7} m (D) 4.0×10^{-7} m

MP0165

4. The ratio of the kinetic energy of the n = 2 electron for the H atom to that of He^+ ion is

(A) $\frac{1}{4}$ (B) $\frac{1}{2}$ (C) 1 (D) 2

MP0165

Paragraph for Question Nos. 5 to 7

When a particle is restricted to move along x-axis between x = 0 and x = a, where a is of nanometer dimension, its energy can take only certain specific values. The allowed energies of the particle moving in such a restricted region, correspond to the formation of standing waves with nodes at its ends x = 0 and x = a. The wavelength of this standing wave is related to the linear momentum p of the particle according to the de Broglie relation. The energy of the particle of mass m is related to its linear momentum as $E = \frac{p^2}{2m}$. Thus, the energy of the particle can be denoted by a quantum number 'n' taking values 1,2,3, ... (n = l, called the ground state) corresponding to the number of loops in the standing wave. Use the model described above to answer the following three questions for a particle moving in the line x = 0 to x = a. Take $h = 6.6 \times 10^{-34}$ Js and $e = 1.6 \times 10^{-19}$ C. **[JEE-2009]**

5. The allowed energy for the particle for a particular value of n is proportional to

(A) a^{-2} (B) $a^{-3/2}$ (C) a^{-1} (D) a^2

MP0166

6. If the mass of the particle is $m = 1.0 \times 10^{-30}$ kg and a = 6.6 nm, the energy of the particle in its ground state is closest to :

(A) 0.8 meV (B) 8 meV (C) 80 meV (D) 800 meV

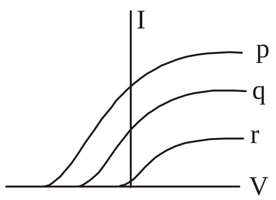
MP0166

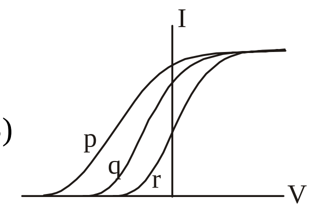
7. The speed of the particle, that can take discrete values, is proportional to

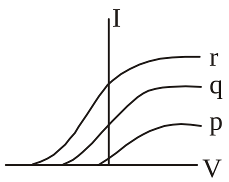
(A) $n^{-3/2}$ (B) n^{-1} (C) $n^{1/2}$ (D) n

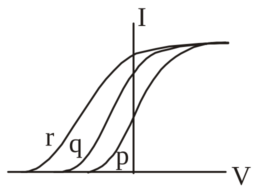
MP0166

8. Photoelectric effect experiments are performed using three different metal plates p, q and r having work functions $\phi_p = 2.0$ eV, $\phi_q = 2.5$ eV and $\phi_r = 3.0$ eV, respectively. A light beam containing wavelengths of 550 nm, 450 nm and 350 nm with equal intensities illuminates each of the plates. The correct I-V graph for the experiment is : **[JEE-2009]**

(A) 

(B) 

(C) 

(D) 

MP0167

9. An α–particle and a proton are accelerated from rest by a potential difference of 100 V. After this, their de Broglie wavelengths are λ_α and λ_p respectively. The ratio $\frac{\lambda_p}{\lambda_\alpha}$, to the nearest integer, is

[JEE 2010]

MP0168

Paragraph for Question Nos. 10 to 12

The key feature of Bohr's theory of spectrum of hydrogen atom is the quantization of angular momentum when an electron is revolving around a proton. We will extend this to a general rotational motion to find quantized rotational energy of a diatomic molecule assuming it to be rigid. The rule to be applied is Bohr's quantization condition. **[JEE 2010]**

10. A diatomic molecule has moment of inertia I. By Bohr's quantization condition its rotational energy in the n^{th} level (n = 0 is not allowed) is

(A) $\frac{1}{n^2}\left(\frac{h^2}{8\pi^2 I}\right)$ (B) $\frac{1}{n}\left(\frac{h^2}{8\pi^2 I}\right)$ (C) $n\left(\frac{h^2}{8\pi^2 I}\right)$ (D) $n^2\left(\frac{h^2}{8\pi^2 I}\right)$

MP0169

11. It is found that the excitation frequency from ground to the first excited state of rotation for the CO molecule is close to $\frac{4}{\pi}\times 10^{11}$ Hz. Then the moment of inertia of CO molecule about its center of mass is close to [Take h = $2\pi \times 10^{-34}$ Js)

(A) 2.76×10^{-46} kg m^2 (B) 1.87×10^{-46} kg m^2

(C) 4.67×10^{-47} kg m^2 (D) 1.17×10^{-47} kg m^2

MP0169

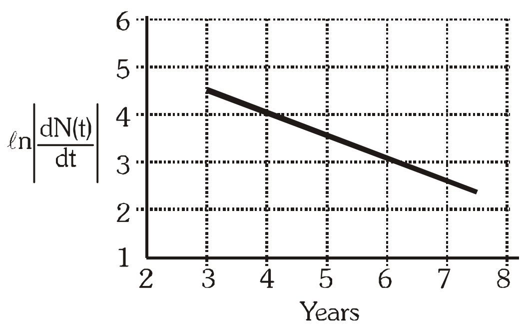
12. In a CO molecule, the distance between C (mass = 12 a.m.u.) and O (mass = 16 a.m.u.),

where 1 a.m.u. = $\frac{5}{3}\times 10^{-27} kg$, is close to

(A) 2.4×10^{-10}m (B) 1.9×10^{-10}m (C) 1.3×10^{-10}m (D) 4.4×10^{-11}m

MP0169

13. To determine the half life of a radioactive element, a student plots a graph of $\ell n\left|\frac{dN(t)}{dt}\right|$ versus t. Here $\frac{dN(t)}{dt}$ is the rate of radioactive decay at time t. If the number of radioactive nuclei of this element decreases by a factor of p after 4.16 years, the value of p is **[JEE 2010]**



MP0170

14. The wavelength of the first spectral line in the Balmer series of hydrogen atom is 6561 Å. The wavelength of the second spectral line in the Balmer series of singly-ionized helium atom is

[JEE 2011]

(A) 1215 Å (B) 1640Å (C) 2430Å (D) 4687Å

MP0171

15. A silver sphere of radius 1 cm and work function 4.7 eV is suspended from an insulating thread in free-space. It is under continuous illumination of 200 nm wavelength light. As photoelectrons are emitted, the sphere gets charged and acquires a potential. The maximum number of photoelectrons emitted from the sphere is A × 10^z (where 1 < A < 10). The value of 'Z' is **[JEE 2011]**

MP0172

16. A proton is fired from very far away towards a nucleus with charge Q = 120 e, where e is the electronic charge. It makes a closest approach of 10 fm to the nucleus. The de Broglie wavelength (in units of fm) of the proton at its start is (Take : The proton mass, $m_p = (5/3) \times 10^{-27}$ kg;

$h/e = 4.2 \times 10^{-15}$ J.s/C; $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9$ m/F; 1 fm = 10^{-15} m) **[JEE 2012]**

MP0173

17. The work functions of Silver and sodium are 4.6 and 2.3 eV, repetitively. The ratio of the slope of the stopping potential versus frequency plot for Silver to that of Sodium is. **[JEE Advanced-2013]**

MP0174

18. The radius of the orbit of an electron in a Hydrogen-like atom is 4.5 a_0, where a_0 is the Bohr radius. Its orbital angular momentum is $\frac{3h}{2\pi}$. It is given that h is Planck constant and R is Rydberg constant. The possible wavelength (s), when the atom de-excites, is (are) :- **[JEE Advanced-2013]**

(A) $\frac{9}{32R}$ (B) $\frac{9}{16R}$ (C) $\frac{9}{5R}$ (D) $\frac{4}{3R}$

MP0175

19. Consider a hydrogen atom with its electron in the n^{th} orbital. An electromagnetic radiation of wavelength 90 nm is used to ionize the atom. If the kinetic energy of the ejected electron is 10.4 eV, then the value of n is (hc = 1242 eV nm). **[JEE Advanced-2015]**

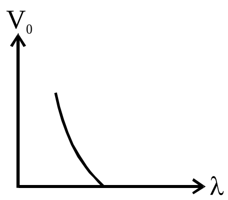
MP0176

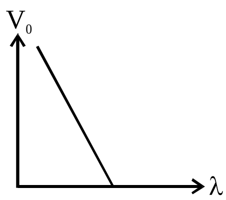
20. Planck's constant h, speed of light c and gravitational constant G are used to form a unit of length L and a unit of mass M. Then the correct option(s) is(are) :- **[JEE Advanced-2015]**

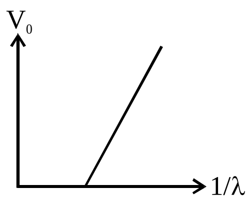
(A) $M \propto \sqrt{c}$ (B) $M \propto \sqrt{G}$ (C) $L \propto \sqrt{h}$ (D) $L \propto \sqrt{G}$

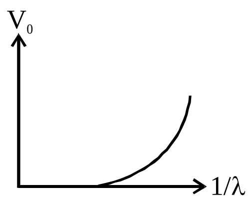
MP0177

21. For photo-electric effect with incident photon wavelength λ, the stopping potential is V_0. Identify the correct variation(s) of V_0 with λ and 1/λ. **[JEE Advanced-2015]**

(A) 

(B) 

(C) 

(D) 

MP0178

22. An electron in an excited state of Li^{2+} ion has angular momentum 3h/2π. The de Broglie wavelength of the electron in this state is $p\pi a_0$ (where a_0 is the Bohr radius). The value of p is

[JEE Advanced-2015]

MP0179

23. In a historical experiment to determine Planck's constant, a metal surface was irradiated with light of different wavelengths. The emitted photoelectron energies were measured by applying a stopping potential. The relevant data for the wavelength (λ) of incident light and the corresponding stopping potential (V_0) are given below: **[JEE Advanced-2016]**

$\lambda(\mu m)$	V_0 (Volt)
0.3	2.0
0.4	1.0
0.5	0.4

Given that $c = 3 \times 10^8\ ms^{-1}$ and $e = 1.6 \times 10^{-19}C$, Planck's constant (in units of J s) found from such an experiment is :

(A) 6.0×10^{-34} (B) 6.4×10^{-34} (C) 6.6×10^{-34} (D) 6.8×10^{-34}

MP0180

24. Highly excited states for hydrogen like atoms (also called Rydberg states) with nuclear charge Ze are defined by their principal quantum number n, where n >> 1. Which of the following statement(s) is (are) true? **[JEE Advanced-2016]**

(A) Relative change in the radii of two consecutive orbitals does not depend on Z

(B) Relative change in the radii of two consecutive oribitals varies as 1/n

(C) Relative change in the energy of two consecutive orbitals varies as $1/n^3$

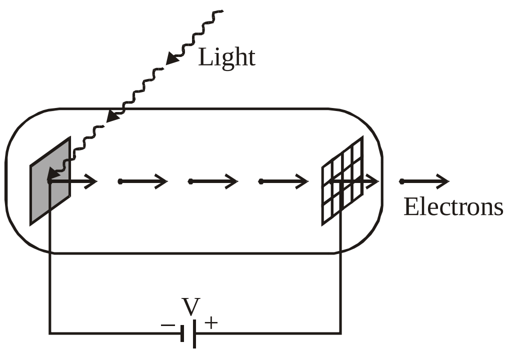
(D) Relative change in the angular momenta of two consecutive orbitals varies as 1/n

MP0181

25. A hydrogen atom in its ground state is irradiated by light of wavelength 970 Å. Taking $hc/e = 1.237 \times 10^{-6}$ eV m and the ground state energy of hydrogen atom as –13.6 eV, the number of lines present in the emission spectrum is **[JEE Advanced-2016]**

MP0182

26. Light of wavelength λ_{ph} falls on a cathode plate inside a vacuum tube as shown in the figure. The work function of the cathode surface is ϕ and the anode is a wire mesh of conducting material kept at a distance d from the cathode. A potential difference V is maintained between the electrodes. If the minimum de Broglie wavelength of the electrons passing through the anode is λ_e, which of the following statement(s) is(are) true ? **[JEE Advanced-2016]**



(A) For large potential difference ($V >> \phi/e$), λ_e is approximately halved if V is made four times

(B) λ_e increases at the same rate as λ_{ph} for $\lambda_{ph} < hc/\phi$

(C) λ_e is approximately halved, if d is doubled

(D) λ_e decreases with increase in ϕ and λ_{ph}

MP0183

27. An electron in a hydrogen atom undergoes a transition from an orbit with quantum number n_i to another with quantum number n_f. V_i and V_f are respectively the initial and final potential energies of the electron. If $\frac{V_i}{V_f} = 6.25$, then the smallest possible n_f is. **[JEE Advanced-2017]**

MP0184

28. A photoelectric material having work-function ϕ_0 is illuminated with light of wavelength $\lambda \left(\lambda < \frac{hc}{\phi_0}\right)$.

The fastest photoelectron has a de-Broglie wavelength λ_d. A change in wavelength of the incident light by $\Delta\lambda$ results in a change $\Delta\lambda_d$ in λ_d. Then the ratio $\Delta\lambda_d/\Delta\lambda$ is proportional to

[JEE Advanced-2017]

(A) λ_d^3/λ^2 (B) λ_d^3/λ (C) λ_d^2/λ^2 (D) λ_d/λ

MP0185

29. In a photoelectric experiment a parallel beam of monochromatic light with power of 200 W is incident on a perfectly absorbing cathode of work function 6.25 eV. The frequency of light is just above the threshold frequency so that the photoelectrons are emitted with negligible kinetic energy. Assume that the photoelectron emission efficinecy is 100% A potential difference of 500 V is applied between the cathode and the anode. All the emitted electrons are incident normally on the anode and are absorbed. The anode experiences a force $F = n \times 10^{-4}$ N due to the impact of the electrons. The value of n is........ Mass of the electron $m_e = 9 \times 10^{-31}$ kg and $1.0 \text{ eV} = 1.6 \times 10^{-19}$ J.? **[JEE Advanced-2018]**

MP0186

30. Consider a hydrogen-like ionized atom with atomic number Z with a single electron. In the emission spectrum of this atom, the photon emitted in the n = 2 to n = 1 transition has energy 74.8 eV higher than the photon emitted in the n = 3 to n = 2 transition. The ionization energy of the hydrogen atom is 13.6 eV. The value of Z is.............. . **[JEE Advanced-2018]**

MP0187

31. A free hydrogen atom after absorbing a photon of wavelength λ_a gets excited from the state n = 1 to the state n = 4. Immediately after that the electron jumps to n = m state by emitting a photon of wavelength λ_e. Let the change in momentum of atom due to the absorption and the emission are Δp_a and Δp_e , respectively. If $\lambda_a/\lambda_e = \frac{1}{5}$. Which of the option(s) is/are correct ?

[Use hc = 1242 eV nm; 1 nm = 10^{-9} m, h and c are Planck's constant and speed of light, respectively]

[JEE Advanced-2019]

(1) $\lambda_e = 418$ nm

(2) The ratio of kinetic energy of the electron in the state n = m to the state n = 1 is $\frac{1}{4}$

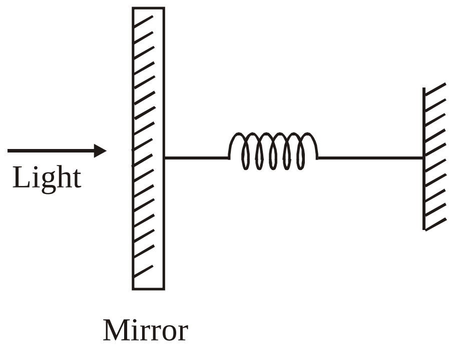
(3) m = 2

(4) $\Delta p_a/\Delta p_e = \frac{1}{2}$

MP0188

32. A perfectly reflecting mirror of mass M mounted on a spring constitutes a spring-mass system of angular frequency Ω such that $\frac{4\pi M\Omega}{h} = 10^{24}\text{m}^{-2}$ with h as Planck's constant. N photons of wavelength $\lambda = 8\pi \times 10^{-6}$m strike the mirror simultaneously at normal incidence such that the mirror gets displaced by 1μm. If the value of N is $x \times 10^{12}$, then the value of x is________.

[Consider the spring as massless] **[JEE Advanced-2019]**



MP0189

CBSE PREVIOUS YEAR'S QUESTIONS

1. Two metals A and B have work functions 4eV and 10 eV respectively. Which metal has lower threshold wavelength'? **[1; CBSE-2004]**

2. Red light, however bright it is, cannot produce the emission of electrons from a clean zinc surface. But even weak ultraviolet radiation can do so. Why?

X-rays of wavelength 'λ' fell on photosensitive surface, emitting electrons. Assuming X-rays of wavelength 'λ' fall on a photo sensitive Surface, emitting be neglected, prove that the de Broglie wavelength of electrons emitted will be $\sqrt{\frac{h\lambda}{2mc}}$

3. Define the terms: 'half-life period' and 'decay constant of a radioactive sample. Derive the relation between these terms. **[3; CBSE-2004]**

4. When a deuteron of mass 20141 u and negligible kinetic energy is absorbed by a lithium $\left({}^{6}_{3}\text{Li}\right)$ nucleus of mass 6.0155 u, the compound nucleus disintegrates spontaneously into two alpha particles, each of mass 4.0026 u. Calculate the energy in joules carried by each alpha particle (lu – 1.66×10^{27} kg). **[3; CBSE-2004]**

5. Ultraviolet light is incident on two photosensitive materials having work functions W_1 and W_2 ($W_1 > W_2$) in which case will the kinetic energy of the emitted electrons be greater? Why? **[1;CBSE-2005]**

6. Mention the significance of Davisson-Germer experiment An α particle and a proton are accelerated from rest through the same potential difference V. Find the ratio of de-Broglie wavelengths associated with them. **[3;CBSE-2005]**

7. (a) Draw the energy level diagram showing the emission of β-particles followed by γ-rays by a ${}^{60}_{27}\text{Co}$ nucleus.

(b) Plot the distribution of kinetic energy of β particles and state why the energy spectrum is continuous. **[3; CBSE-200S]**

8. A radioactive sample contains 2.2 mg of pure ${}^{11}_{6}\text{C}$ which has half-life period of 1224 seconds. Calculate

(i) The number of atoms present initially.

(ii) The activity when 5μg of the sample will be left. **[3; CBSE-2005]**

9. De-Broglie wavelength associated with an electron accelerated through a potential difference V is λ. What will be its wavelength when the accelerating potential is increased to 4 V? **[1; CBSE-2006]**

10. Sketch a graph between frequency of incident radiations and stopping potential for a given photosensitive material. What information can be obtained from the value of the intercept on the potential axis?

A source of light of frequency greater than the threshold frequency is placed at a distance of 1 m from the cathode of a photo-cell. The stopping potential is found to be V. If the distance of the light source from the cathode is reduced, explain giving reasons, what change will you observe in the

(i) photoelectric current,

(ii) stopping potential. **[3; CBSE-2006]**

11. Define the terms half-life period and decay constant of a radioactive substance. Write their S.I. units. Establish the relationship between the two. **[3; CBSE-2006]**

12. A neutron is absorbed by a ${}_{3}^{6}\text{Li}$ nucleus with the subsequent emission of an alpha particle.

(i) Write the corresponding nuclear reaction.
(ii) Calculate the energy released, in MeV, in this reaction.

Given mass ${}_{3}^{6}\text{Li}$ = 6.0l5l26 u; mass (neutron) = 1.0086654 u; mass (alpha particle) = 4.0026044 u and mass (triton) = 3.0100000u. Take 1u = 931 MeV/c^2. **[3; CBSE-2006]**

13. Ultraviolet radiations of different frequencies v_1 and v_2 are incident on two photosensitive materials having work functions W_1 and W_2 ($W_1 > W_2$) respectively. The kinetic energy of the emitted electrons is same in both the cases. Which one of the two radiations will be of higher frequency ?

[1; CBSE-2007]

14. Define the term 'activity' of radionuclide. Write its SI unit. **[1; CBSE-2007]**

15. Draw a graph showing the variation of potential energy between a pair of nucleons as a function of their separation. Indicate the regions in which the nuclear force is (i) attractive, (ii) repulsive.

[2; CBSE-2007]

16. Draw a schematic diagram of the experimental arrangement used by Davisson and Germer to establish the wave nature of electrons. Explain briefly how the de-Broglie relation was experimentally verified in case of electrons. **[3; CBSE-2007]**

17. Draw the graph to show variation of binding energy per nucleon with mass number of different atomic nuclei. Calculate binding energy/nucleon of ${}_{20}^{40}\text{Ca}$ nucleus.

Given:

mass of ${}_{20}^{40}\text{Ca}$ = 39.962589 u

mass of ${}_{20}^{40}\text{Ca}$ proton = 1.007825 u

mass of neutron – 1.008665 u and 1u = 931 MeV/C^2 **[3; CBSE-2007]**

18. An electron and alpha particle have the same de-Broglie wavelength associated with them How are their kinetic energies related to each other? **[1; CBSE-2008]**

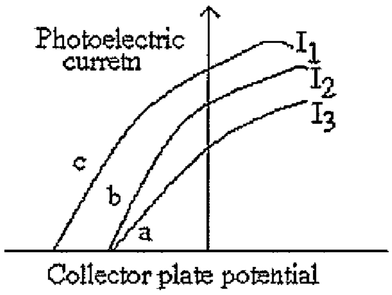
19. A nucleus ${}_{10}^{23}\text{Ne}$ undergoes decay and becomes ${}_{11}^{23}\text{Na}$. Calculate the maximum kinetic energy of electrons emitted assuming that the daughter nucleus and anti-neutrino carry negligible kinetic energy.

$$\left\{\begin{array}{l}\text{Mass of } {}_{10}^{23}\text{Ne} = 22.994455\text{u} \\ \text{Mass of } {}_{11}^{23}\text{Na} = 22.989770\text{u} \\ 1\text{u} = 931.5\text{MeV}/\text{c}^2\end{array}\right\}$$

[2; CBSE-2008]

20. An electromagnetic wave of wavelength λ is incident on a photosensitive surface of negligible work function. If the photo-electrons emitted from this surface have the de-Broglie wavelength λ_1 prove that $\lambda = \left(\frac{2\text{mc}}{\text{h}}\right)\lambda_1^2$ **[3; CBSE-2008]**

21. The figure shows a plot of three curves a, b, c showing the variation of photocurrent vs collector plate potential for three different intensities I_1, I_2 and I_3 having frequencies v_1, v_2 and v_3 respectively incident on a photosensitive surface. Point out the two curves of which the incident radiations have same frequency but different intensities. **[1; CBSE-2009]**



22. Two nuclei have mass numbers in the ratio 1 :3. What is the ratio of their nuclear densities? **[1; CBSE-2009]**

23. A radioactive nucleus 'A' Undergoes a series of decays according to the following scheme:

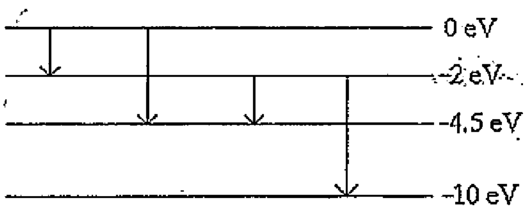
$$A \xrightarrow{\alpha} A_1 \xrightarrow{\beta} A_2 \xrightarrow{\alpha} A_3 \xrightarrow{\gamma} A_4$$

The mass number and atomic number of A4 are 172 and 69 respectively. What are these numbers for A? **[2; CBSE-2009]**

24. An electron and a proton are accelerated through the potential. Which one of the two has (i) greater . value of de-Broglie wavelength associated with it and (ii) less momentum? Justify your answer. **[3; CBSE-2009]**

25. (a) The energy levels of an atom are as shown below. Which of them will result in the transition of a photon of wavelength 275 nm?

(h) Which transition corresponds to emission of radiation of maximum wavelength? **[3; CBSE-2009]**



26. Define ionisation energy. What is its value for a hydrogen atom ? **[1; CBSE-2010]**

27. An α-particle and a proton are accelerated from rest by the same potential. Find the ratio of their de-Broglie wavelengths. **[2;CBSE-2010]**

28. Write Einstein's photoelectric equation. State clearly the three salient features observe in photoelectric effect, which can be explained on the basis of the above equation. **[2; CBSE-2010]**

29. Draw a plot of potential energy of a pair of nucleons as a function of their separation. Write two important conclusions which you can draw regarding the nature of nuclear forces. **[2; CBSE-2010]**

30. Draw a plot of the binding energy per nucleon as a function of mass number for a large number of nuclei, $2 \le A \le 240$. How do you explain the constancy of binding energy per nucleon in the range $30 < A < 170$ using the property that nuclear force is short-ranged ? **[2; CBSE-2010]**

31. (a) Write symbolically the β^- decay process of $^{32}_{15}P$.

(b) Derive an expression for the average life of a radionuclide. Give its relationship with the half-life. **[3; CBSE-2010]**

32. Write any two characteristic properties of nuclear force. **[1; CBSE-2011]**

33. Define the term 'stopping potential' in relation to photoelectric effect. **[1; CBSE-2011]**

34. Using the curve for the binding energy per nucleon as a function of mass number A, state clearly how the release in energy in the processes of nuclear fission and nuclear fusion can be explained. **[2; CBSE-2011]**

35. Draw a plot showing the variation of photoelectric current with collector plate potential for two different frequencies, $v_1 > v_2$, of incident radiation having the same intensity. In which case will the stopping potential be higher? Justify your answer. **[3; CBSE-2011]**

36. (a) Using de-Broglie's hypothesis, explain with the help of a suitable diagram, Bohr's second postulate of quantization of energy levels in a hydrogen atom,

(b) The ground state energy of hydrogen atom is –13.6eV. What are the kinetic and potential energies of the electron in this state? **[3; CBSE-2011]**

37. Define the terms (i) 'cut-off Voltage' and (ii) 'threshold frequency' in relation to the phenomenon of photoelectric effect

Using Eintein's photoelectric equation shows how the cut-off voltage and threshold frequency for a given photosensitive material can be determined with the help of a suitable plot/graph. **[3; CBSE-2012]**

38. Draw a plot of potential energy of a pair of nucleons as a function of their separations. Mark the regions where the nuclear is (i) attractive and (ii) repulsive. Write any two characteristic features of nuclear forces. **[3; CBSE-2012]**

39. In a Geiger-Marsden experiment, calculate the distance of closest approach to the nucleus of Z = 80, when a α-particle of 8Mev energy impinges on it before it comes momentarily to rest and reverses its direction.

How will the distance of closest approach be affected when the kinetic energy of the α-particle is doubles?

OR

The ground state energy of hydrogen atom is –13.6 eV. If an electron make a transition from the energy level –0.85 eV to –3.4 eV, calculate spectrum does his wavelength belong?**[3; CBSE-2012]**

40. Define the activity of a given radioactive substance. Write its S.I. unit. **[CBSE-2013]**

41. Write the expression for the deBroglie wavelength associated with a charged particle having charge 'q' and mass 'm', when it is accelerated by a potential V. **[CBSE-2013]**

42. Write Einstein's photoelectric equation and point out any two characteristic properties of photons on which this equation is based. Briefly explain the three observed features which can be explained' by this equation. **[CBSE-2013]**

43. Using Bohr's postulates, derive the expression for the frequency of radiation emitted when electron in hydrogen atom undergoes transition from higher energy state (quantum number n,) to the lower state, (n_f). When electron in hydrogen atom jumps from energy state $n_i = 4$ to $n_f = 3,2,1$, identify the spectral series to which the emission lines belong. **[CBSE-2013]**

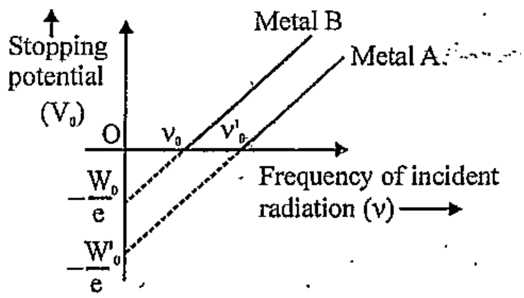
OR

(a) Draw the plot of binding energy per nucleon (BE/A) as a function of mass number A. Write two important conclusions that can be drawn regarding the nature of nuclear force.

(b) Use this graph to explain the release of energy in both the processes of nuclear fusion and fission,

(c) Write the basic nuclear process of neutron undergoing β-decay. Why is the detection of neutrinos found very difficult?

44. The graph shows the variation of stopping potential with frequency of incident radiation for two photosensitive metals A and B. Which one of the two has higher value of work-function? Justify your answer. **[CBSE-2014]**



45. Why is it found experimentally difficult to detect neutrinos in nuclear β-decay ? **[CBSE-2014]**

46. Using Rutherford model of the atom, derive the expression for the total energy of the electron in hydrogen atom. What is the significance of total negative energy possessed by the electron? **[CBSE-2014]**

OR

Using Bohr's postulates of the atomic model, derive the expression for radius of n^{th} electron orbit. Hence obtain the expression for Bohr's radius. **[CBSE-2014]**

47. When the electron orbiting in hydrogen atom in its ground state moves to the third excited state, show how the de Broglie wavelength associated with it would be affected. **[CBSE-2015]**

48. Define the terms 'stopping potential' and 'threshold frequency' in relation to photoelectric effect. How does one determine these physical quantities using einstein's equation ? **[CBSE-2015]**

49. A proton and an α particle are accelerated through the same potential difference. Which one of the two has (i) greater de-Broglie wavelength, and (ii) less kinetic energy ? Justify your answer. **[2 ; CBSE-2016]**

50. When is H_α line in the emission spectrum of hydrogen atom obtained ? Calculate the frequency of the photon emitted during this transition. **[2 ; CBSE-2016]**

OR

Calculate the wavelength of radiation emitted when electron in a hydrogen atom jumps from $n = \infty$ to $n = 1$. **[2 ; CBSE-2016]**

51. State two important properties of photon which are used to write Einstein's photoelectric equation. Define (i) stopping potential and (ii) threshold frequency, using Einstein's equation and drawing necessary plot between relevant quantities. **[3 ; CBSE-2016]**

52. (a) Derive the mathematical expression for law of radioactive decay for a sample of a radioactive nucleus. **[3 ; CBSE-2016]**

(b) How is the mean life of a given radioactive nucleus related to the decay constant ?

53. A 12·5 eV electron beam is used to excite a gaseous hydrogen atom at room temperature. Determine the wavelengths and the corresponding series of the lines emitted. **[CBSE-2017]**

54. Using photon picture of light, show how Einstein's photoelectric equation can be established. Write two features of photoelectric effect which cannot be explained by wave theory. **[CBSE-2017]**

55. Draw graphs showing variation of photoelectric current with applied voltage for two incident radiations of equal frequency and different intensities. Mark the graph for the radiation of higher intensity.

[CBSE-2018]

56. Four nuclei of an element undergo fusion to form a heavier nucleus, with release of energy. Which of the two – the parent or the daughter necleus – would have higher binding energy per nucleon?

[CBSE-2018]

57. If light of wavelength 412.5 nm is incident on each of the metals given below, which ones will show photoelectric emission and why? **[CBSE-2018]**

Metal	Work Function (eV)
Na	1.92
K	2.15
Ca	3.20
Mo	4.17

58. (a) State Bohr's psotulate to define stable orbits in hydrogen atom. How does de-Broglie's hypothesis explain the stability of these orbits?

(b) A hydrogen atom initially in the grond state absorbs a photon which excites it to the n = 4 level. Estimate the frequency of the photon. **[CBSE-2018]**

59. (a) Explain the processes of nuclear fission and nuclear fusion by using the plot of binding energy per nucleon (BE/A) versus the mass number A.

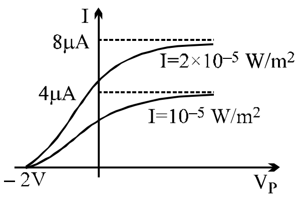
(b) A radioactive isotope has a half-lift of 10 years. How long will it take for the activity to resuce to 3.125%? **[CBSE-2018]**

ANSWER KEY

EXERCISE (S-1)

1. Ans. 6.59×10^{-34} Js **2. Ans.** (a) 3.38×10^{-19} J = 2.11 eV (b) 3.0×10^{20} photons/s

3. Ans.



4. Ans. Use $eV_0 = h\nu - \phi_0$ for both sources. From the data on the first source, ϕ_0 = 1.40 eV. Use the value to obtain for the second suorce V_0 = 1.50 V.

5. Ans. (a) 3.14×10^{-19} J , 1.05×10^{-27} kg m/s (b) 3×10^{16} photons/s (c) 0.63 m/s

6. Ans. (a) 4.04×10^{-24} kg ms^{-1} (b) 0.164 nm

7. Ans. (a) 6.95×10^{-25} J = 4.34 μeV (b) 3.78×10^{-28} J = 0.236 neV

8. Ans. (a) 6.686×10^{-21} J = 4.174×10^{-2} eV (b) 0.145 nm

9. Ans. $\sqrt{2}$ **10. Ans.** 4 **11. Ans.** 0.55 eV **12. Ans.** 7

13. Ans. 2 **14. Ans.** 820 nm.

15. Ans. Lyman series: 103 nm and 122 nm; Balmer series: 656 nm.

16. Ans. (a) +3.4 eV; (b) –6.8 eV; (c) potential energy

17. Ans. 2.56×10^{-13} m; –2.8 keV **18. Ans.** 8 **19. Ans.** n = 24

20. Ans. 2

21. Ans. Use $\lambda = (hc/E)$ with $E = 5.1 \times 1.602 \times 10^{-10}$ J to get $\lambda = 2.43 \times 10^{-16}$ m.

22. Ans. 6210 eV **23. Ans.** 400

EXERCISE (S-2)

1. Ans. 5 **2. Ans.** 1 **3. Ans.** 1.1×10^{12}

4. Ans. (a) $10^5\ s^{-1}$; (b) 286.18; (d) 111 s **5. Ans.** $\lambda = \dfrac{2\lambda_1\lambda_2}{\sqrt{\lambda_1^2 + \lambda_2^2}}$

6. Ans. KE ≅ 151 eV, d_{least} = 0.5 Å **7. Ans.** (i) 2 ; (ii) 13.6 eV ; (iii) 12.75 eV, 0.66 eV

8. Ans. 6.8 eV, 5×10^{15} Hz

9. Ans. (i) Allowed values of energy of neutron = 6.36 eV and 0.312 eV ; Allowed values of energy of He atom = 17.84 eV and 16.328 eV, (ii) 18.23×10^{14} Hz , 9.846×10^{15} Hz, 11.6×10^{15} Hz

10. Ans. 7.4 eV, 4.7 Volts **11. Ans.** 6 **12. Ans.** 255 **13. Ans.** 3 **14. Ans.** 159

15. Ans. 255 **16. Ans.** 2 **17. Ans.** 98.25 eV

18. Ans. (i) 0.62Å, (ii) No, (iii) Yes 0.8 Å **19. Ans.** 41

EXERCISE (O-1)

1. Ans. (A) 2. Ans. (A) 3. Ans. (B) 4. Ans. (B) 5. Ans. (B) 6. Ans. (C)
7. Ans. (A) 8. Ans. (A) 9. Ans. (D) 10. Ans. (B) 11. Ans. (B) 12. Ans. (A)
13. Ans. (B) 14. Ans. (B) 15. Ans. (D) 16. Ans. (D) 17. Ans. (D) 18. Ans. (A)
19. Ans. (D) 20. Ans. (A) 21. Ans. (C) 22. Ans. (D) 23. Ans. (D) 24. Ans. (B)
25. Ans. (A) 26. Ans. (A) 27. Ans. (A) 28. Ans. (A) 29. Ans. (A) 30. Ans. (A)
31. Ans. (A) 32. Ans. (D) 33. Ans. (B) 34. Ans. (A) 35. Ans. (B) 36. Ans. (B)
37. Ans. (D) 38. Ans. (B) 39. Ans. (A) 40. Ans. (A) 41. Ans. (D) 42. Ans. (B)
43. Ans. (C) 44. Ans. (D) 45. Ans. (D) 46. Ans. (D) 47. Ans. (C) 48. Ans. (D)
49. Ans. (C) 50. Ans. (A) 51. Ans. (C) 52. Ans. (A,B,C) 53. Ans. (A,B,D)
54. Ans. (A,C) 55. Ans. (A,B,C) 56. Ans. (B,C,D) 57. Ans. (A,D)
58. Ans. (A,B,C,D) 59. Ans. (A,B,D) 60. Ans. (A,B,C,D) 61. Ans. (B, D)
62. Ans. (A,C,D) 63. Ans. (A,B,C) 64. Ans. (A,C,D) 65. Ans. (A,C,D)
66. Ans. (B) 67. Ans. (A,C) 68. Ans. (A,C,D) 69. Ans. (A,B,C,D)
70. Ans. (A, B, C) 71. Ans. (A, C) 72. Ans. (A) P,R,S (B) P,Q (C) P,Q (D) R,S
73. Ans. (A)-QR, (B)-PS, (C)-QS, (D)-PR
74. Ans. (A) →(P,R) ; (B) →(Q,S) ; (C) →(Q, S) ; (D)→(P,R) 75. Ans. (B)
76. Ans. (A)→ (S); (B) → (R); (C) → (Q); (D) → (P)

EXERCISE (O-2)

1. Ans. (D) 2. Ans. (C) 3. Ans. (A) 4. Ans. (B,D) 5. Ans. (B) 6. Ans. (A)
7. Ans. (B) 8. Ans. (D) 9. Ans. (C) 10. Ans. (C) 11. Ans. (D) 12. Ans. (B)
13. Ans. (B) 14. Ans. (B) 15. Ans. (D) 16. Ans. (A,C,D) 17. Ans. (D)
18. Ans. (A,B) 19. Ans. (B,C,D) 20. Ans. (B, C) 21. Ans. (A, B, D)
22. Ans. (B, C) 23. Ans. (B,C) 24. Ans. (A,C,D) 25. Ans. (A)
26. Ans. (A) 27. Ans. (B) 28. Ans. (A) 29. Ans. (A) 30. Ans. (B) 31. Ans. (B)
32. Ans. (C) 33. Ans. (B) 34. Ans. (C) 35. Ans. (D) 36. Ans. (A)

EXERCISE (JM)

1. Ans. (2) 2. Ans. (2) 3. Ans. (4) 4. Ans. (1) 5. Ans. (2) 6. Ans. (1)
7. Ans. (2) 8. Ans. (1) 9. Ans. (4) 10. Ans. (4) 11. Ans. (3) 12. Ans. (1)
13. Ans. (2) 14. Ans. (3) 15. Ans. (2) 16. Ans. (4) 17. Ans. (3)

EXERCISE (JA)

1. Ans. (B) 2. Ans. (C) 3. Ans. (C) 4. Ans. (A) 5. Ans. (A) 6. Ans. (B)
7. Ans. (D) 8. Ans. (A) 9. Ans. 3 10. Ans. (D) 11. Ans. (B) 12. Ans. (C)
13. Ans. 8 14. Ans. (A) 15. Ans. 7 16. Ans. 7 17. Ans. 1 18. Ans. (A, C)
19. Ans. 2 20. Ans. (A), (C), (D) 21. Ans. (A,C) 22. Ans. 2 23. Ans. (B)
24. Ans. (A, B, D) 25. Ans. 6 26. Ans. (A) 27. Ans. 5 28. Ans. (A)
29. Ans. 24 [23.60, 24.40] 30. Ans. 3 [3,3] 31. Ans. (2,3) 32. Ans. (1.00)