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.

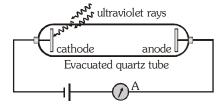
EXPLANATION OF PHOTOELECTRIC EFFECT

- 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=hv, where h is the Plank's constant and v 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 hv. 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

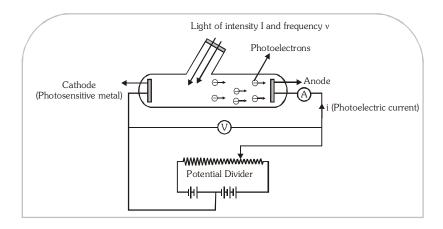
Hertz observed that when ultraviolet rays are incident on negative plate of electric discharge tube then conduction takes place easily in the tube.



- 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)

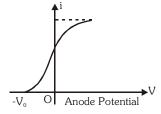
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• Experimental study of photoelectric Effect: When light of frequency v and intensity I falls on the cathode, electrons are emitted from it. The electrons are collected by the anode and a current flows in the circuit. This current is called photoelectric 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

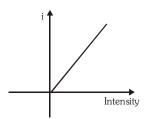
With the help of the above experimental setup, a graph is obtained between current and potential difference. The potential difference is varied with the help of a potential divider. The graph obtained is shown below. The main points of observation are:



- (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 emitted 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

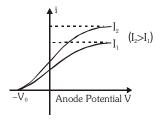
The photoelectric current is found to be directly proportional to intensity of incident radiation.





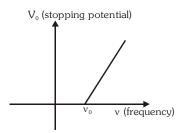
(iii) Effect of intensity on saturation current and stopping potential

- (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 v_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, $v > v_0$.



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

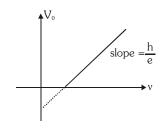
Einstein explained photoelectric effect on the basis of photon—electron interaction. The energy transfer takes place due to collisions between an electrons and a photon. The electrons within the target material are held there by electric force. The electron needs a certain minimum energy to escape from this pull. This minimum energy is the property of target material and it is called the work function. When a photon of energy E=hv 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 $hv = \phi + KE_{max}$

Here $h\nu$ 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)

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



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

$$v_{max} = \sqrt{\frac{2\left(\frac{hc}{\lambda} - \phi\right)}{m}} = \sqrt{\frac{2\left(\frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{4.36 \times 10^{-7}} - 1.24 \times 1.6 \times 10^{-19}\right)}{9.11 \times 10^{-31}}} = 7.523 \times 10^{5} \text{ m/s}$$

 \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 $eV_0 = \frac{1}{2} m v_{\text{max}}^2$

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

- **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.

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)
$$\frac{hc}{\lambda} - \frac{hc}{\lambda_0} = (n+1)\frac{hc}{n\lambda} - (n+1)\frac{hc}{\lambda_0} \implies \frac{nhc}{\lambda_0} = \frac{hc}{n\lambda} \implies \lambda_0 = n^2\lambda$$

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. (: $\lambda_R > \lambda_V$)

• According to Planck the energy of a photon is directly proportional to the frequency of the radiation.

$$E \propto v$$

or

$$E = hv$$

$$E = \frac{hc}{\lambda}$$
 joule (:: $c = v\lambda$) or

$$E = \frac{hc}{\lambda e} = \frac{12400}{\lambda} eV - Å$$

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

Here E = energy of photon, c = speed of light, h = Planck's constant, e = charge of electron $h = 6.62 \times 10^{-34} \text{ J-s}$, v = frequency of photon, $\lambda =$ wavelength of photon

- Linear momentum of photon $p = \frac{E}{c} = \frac{hv}{c} = \frac{h}{\lambda}$
- 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
$$I = \frac{E}{At} = \frac{P}{A}$$

Here P = power of source,

A = Area, t = time taken

E = energy incident in t time = Nhv,

N = number of photon incident in t time

Intensity
$$I = \frac{N(hv)}{At} = \frac{n(hv)}{A}$$

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

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

• When photons fall on a surface, they exert a force and pressure on the surface. This pressure is called radiation pressure.

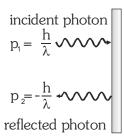
• Force exerted on perfectly reflecting surface

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

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

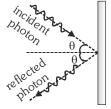
$$F = \frac{P}{c} \left(\because n = \frac{P\lambda}{hc} \right)$$
 and Pressure $= \frac{F}{A} = \frac{P}{Ac} = \frac{I}{c}$

incident photon
$$p_1 = \frac{h}{\lambda}$$
 no reflected photon $p_2 = 0$

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



- Ex. The intensity of sunlight on the surface of earth is 1400 W/m². Assuming the mean wavelength of sunlight to be 6000 Å, calculate:-
 - (a) The photon flux arriving at 1 m² 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
$$E = \frac{hc}{\lambda} = \frac{12400}{6000} = 2.06 \text{ eV} = 3.3 \times 10^{-19} \text{ J}$$

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

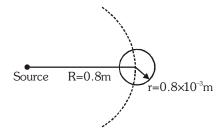
:. number of photons emitted per second n =
$$\frac{P}{E} = \frac{3.2 \times 10^{-3}}{8 \times 10^{-19}} = 4 \times 10^{15} / s$$

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

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

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

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



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

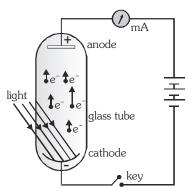
As
$$KE_{max} = 2.0 \text{ eV} \Rightarrow \text{Stopping potential V}_0 = 2V \Rightarrow 2 = \frac{q}{4\pi\epsilon_0 r} \Rightarrow q = 1.78 \times 10^{-12} \text{ C}$$

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

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 ($\lambda \approx 10^{-5}$ 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 $m_e = 9.1 \times 10^{-31} \text{ kg}$, $q = 1.6 \times 10^{-19} \text{ C}$, $h = 6.62 \times 10^{-34} \text{ J-s}$

De Broglie wavelength associated with electron $\lambda = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \text{ V}}}$

$$\lambda = \frac{12.27 \times 10^{-10}}{\sqrt{V}} \, meter \, = \frac{12.27}{\sqrt{V}} \, \stackrel{\circ}{A} \quad so \quad \lambda \propto \frac{1}{\sqrt{V}}$$

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



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

$$\lambda_p = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 1.67 \times 10^{-27} \times 1.6 \times 10^{-19} \, V}} \; ; \\ \lambda_p = \frac{0.286 \times 10^{-10}}{\sqrt{V}} \, meter = \frac{0.286}{\sqrt{V}} \; \mathring{A}$$

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

$$\lambda_{_{d}} = \frac{6.62 \times 10^{^{-34}}}{\sqrt{2 \times 2 \times 1.67 \times 10^{^{-27}} \times 1.6 \times 10^{^{-19}} V}} \, = \frac{0.202}{\sqrt{V}} \, \mathring{A}$$

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

$$\therefore \lambda_{\alpha} = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 4 \times 1.67 \times 10^{-27} \times 2 \times 1.6 \times 10^{-19} \, V}} \ = \frac{0.101}{\sqrt{V}} \ \mathring{A}$$

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 $\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$

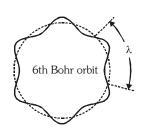
Kinetic energy of the particle in terms of its wavelength $E = \frac{h^2}{2m\lambda^2} = \frac{h^2}{2m\lambda^2 \times 1.6 \times 10^{-19}} eV$

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

$$\therefore \ \lambda = \frac{6.62 \times 10^{-34}}{\sqrt{2} \times 1.67 \times 10^{-27} \times E} \ = \frac{0.286 \times 10^{-10}}{\sqrt{E}} meter \sqrt{eV} \ = \frac{0.286}{\sqrt{E}} \mathring{A} \sqrt{eV}$$

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, $2\pi r = n\lambda$



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

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

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

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

Ex. An α -particle moves in circular path of radius 0.83 cm in the presence of a magnetic field of 0.25 Wb/m². Find the De Broglie wavelength associated with the particle.

Sol.
$$\lambda = \frac{h}{p} = \frac{h}{gBr} = \frac{6.62 \times 10^{-34}}{2 \times 1.6 \times 10^{-19} \times 0.25 \times 83 \times 10^{-4}}$$
 meter = 0.01 Å $\left[\because \frac{mv^2}{r} = qvB\right]$

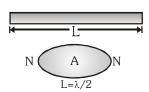
Ex. A proton and an α -particle are accelerated through same potential difference. Find the ratio of their de-Broglie wavelength.

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

For
$$\alpha$$
-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) N A N Since de–Broglie wavelengths are
$$\lambda_n = \frac{h}{p_n}$$

$$p_n = \frac{h}{\lambda_n} = \frac{nh}{2L}, \quad n = 1, 2, 3.... \qquad N \bigcirc A \bigcirc A \bigcirc A \bigcirc N \bigcirc A \bigcirc N$$

(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.

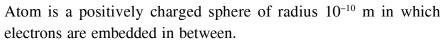
All atoms of same element are identical physically as well as chemically, whereas atoms of different elements are different in properties.

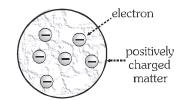
The atoms of different elements are made up of hydrogen atoms. (The radius of the heaviest atom is about 10 times that of hydrogen atom and its mass is about 250 times that of hydrogen).

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.





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

Shortcomings of Thomson's model

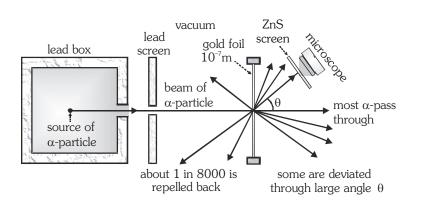
- (i) The spectrum of atoms cannot be explained with the help of this model
- (ii) Scattering of α -particles cannot be explained with the help of this model

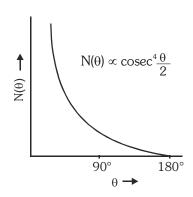
(iii) Angular frequency of electron in
$$n^{th}$$
 orbit $\omega_n = \frac{8\pi^2 k^2 Z^2 e^4 m}{n^3 h^3} \Rightarrow \omega_n \propto \frac{Z^2 m}{n^3}$

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:





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- 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 10⁻¹³m 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

$$N_{_{\theta}} = \frac{N_{_{0}} nt(2Ze^{2})^{2}}{16(4\pi\epsilon_{_{0}})^{2}r^{2}(mv_{_{0}}^{2})^{2}} \times \frac{1}{\sin^{4}\frac{\theta}{2}}$$

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

n = Number of target atom per m^3

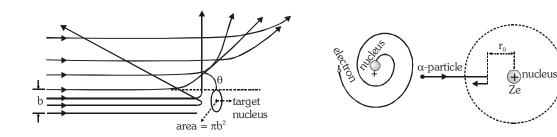
t = Thickness of target

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.



$$r_{0} = \frac{1}{4\pi\epsilon_{0}} \times \frac{(2Ze)^{2}}{\left\lceil\frac{1}{2}mv_{0}^{2}\right\rceil} = \frac{1}{4\pi} \frac{(2Ze)^{2}}{E_{K}} \quad \text{ where } E_{K} = K.E. \text{ of } \alpha\text{-particle}$$

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.

Nucleus

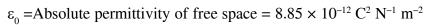
Electron

ALLEN

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. $\frac{1}{4\pi\epsilon_0} \frac{(Ze)e}{r^2} = \frac{mv^2}{r} ...(i)$

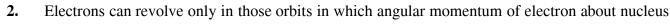


m = Mass of electron

v = Velocity (linear) of electron

r = Radius of the orbit in which electron is revolving.

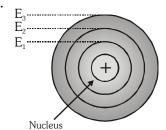
Z = Atomic number of hydrogen like atom.



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. $E_n E_m = hv_{n,m}$



where, $E_n = Outer energy state$

 $E_m = Inner energy state$

 $v_{n m}$ = 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.,
$$\frac{1}{4\pi\epsilon_0} \frac{(Ze)e}{r^2} = \frac{mv^2}{r}$$
 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

$$\frac{1}{4\pi\epsilon_0}Ze^2 = \left(\frac{nh}{2\pi}\right)\times v \ \, \Rightarrow v = \frac{Z}{n}\bigg\lceil\frac{e^2}{2\epsilon_0h}\bigg\rceil = \frac{Z}{n}v_0\,....(iii)$$

Where,
$$v_0 = \frac{\left(1.6 \times 10^{-19}\right)^2}{2 \times 8.85 \times 10^{-12} \times 6.625 \times 10^{-34}} = 2.189 \times 10^6 \text{ ms}^{-1} = \frac{c}{137} = 2.2 \times 10^6 \text{ m/s}$$

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

$$m \left(\frac{Z}{n} \times \frac{e^2}{2\epsilon_0 h} \right) r = \frac{nh}{2\pi} \Rightarrow r = \frac{n^2}{Z} \left[\frac{\epsilon_0 h^2}{\pi m e^2} \right] = \frac{n^2}{Z} r_0 ... (iv)$$

where
$$r_0 = \frac{8.85 \times 10^{-12} \times \left(6.625 \times 10^{-34}\right)^2}{3.14 \times 9.11 \times 10^{-31} \times \left(1.6 \times 10^{-19}\right)^2} = 0.529 \times 10^{-10} \text{ m} \approx 0.53 \text{Å}$$

3. Total energy of electron in nth orbit :

From equation (i) K.E. =
$$\frac{1}{2}$$
 mv² = $\frac{Ze^2}{8\pi\epsilon_0 r}$ and PE = $\frac{1}{4\pi\epsilon_0}\frac{(Ze)(-e)}{r}$ = -2K.E. \therefore |PE| = 2 KE

Total energy of the system E = KE + PE =
$$-2KE + KE = -KE = \frac{-Ze^2}{8\pi\epsilon_0 r}$$

By putting the value of r from the equation (iv), we get $E = \frac{Z^2}{n^2} \left(-\frac{me^4}{8\epsilon_0^2 h^2} \right) = \frac{Z^2}{n^2} \cdot E_0 ...(v)$

where
$$E_0 = \frac{-\left(9.11 \times 10^{-3}\right)\left(1.6 \times 10^{-19}\right)^4}{8 \times \left(8.85 \times 10^{-12}\right)^2 \times \left(6.625 \times 10^{-34}\right)^2} = -13.6 \ eV$$

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

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

where,
$$T_0 = \frac{4 \times \left(8.85 \times 10^{-12}\right)^2 \times \left(6.625 \times 10^{-34}\right)^3}{9.11 \times 10^{-31} \times \left(1.6 \times 10^{-19}\right)^4} = 1.51 \times 10^{-16} \text{ second}$$

5. Frequency of revolution in nth orbit :

$$f = \frac{1}{T} = \frac{Z^2}{n^3} \times \frac{me^4}{4\epsilon_0^2 h^3} = \frac{Z^2}{n^3} \cdot f_0 \text{ where, } f_0 = \frac{9.11 \times 10^{-31} \times \left(1.6 \times 10^{-19}\right)^4}{4 \times \left(8.85 \times 10^{-12}\right)^2 \left(6.625 \times 10^{-34}\right)^3} = 6.6 \times 10^{15} \ Hz$$

6. Wavelength of photon

$$\Delta E = E_{n_2} - E_{n_1} = \frac{me^4}{8\epsilon_0^2 h^2} \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] Z^2 = 13.6 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] Z^2 \\ \Longrightarrow \Delta E = \frac{hc}{\lambda} \\ \Longrightarrow \frac{1}{\lambda} = \overline{\nu} = \frac{me^4}{8\epsilon_0^2 h^3 c} \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] Z^2 \\ \Longrightarrow \Delta E = \frac{hc}{\lambda} \\ \Longrightarrow \frac{1}{\lambda} = \overline{\nu} = \frac{me^4}{8\epsilon_0^2 h^3 c} \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] Z^2 \\ \Longrightarrow \Delta E = \frac{hc}{\lambda} \\ \Longrightarrow \frac{1}{\lambda} = \overline{\nu} = \frac{me^4}{8\epsilon_0^2 h^3 c} \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] Z^2 \\ \Longrightarrow \Delta E = \frac{hc}{\lambda} \\ \Longrightarrow \frac{1}{\lambda} = \overline{\nu} = \frac{me^4}{8\epsilon_0^2 h^3 c} \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] Z^2 \\ \Longrightarrow \Delta E = \frac{hc}{\lambda} \\ \Longrightarrow \frac{1}{\lambda} = \overline{\nu} = \frac{me^4}{8\epsilon_0^2 h^3 c} \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] Z^2 \\ \Longrightarrow \Delta E = \frac{hc}{\lambda} \\ \Longrightarrow \frac{1}{\lambda} = \overline{\nu} = \frac{me^4}{8\epsilon_0^2 h^3 c} \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] Z^2 \\ \Longrightarrow \Delta E = \frac{hc}{\lambda} \\ \Longrightarrow \frac{1}{\lambda} = \frac{1}{\lambda} = \frac{me^4}{8\epsilon_0^2 h^3 c} \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] Z^2 \\ \Longrightarrow \Delta E = \frac{hc}{\lambda} \\ \Longrightarrow \frac{1}{\lambda} = \frac{1}{\lambda} = \frac{me^4}{8\epsilon_0^2 h^3 c} \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right] Z^2 \\ \Longrightarrow \Delta E = \frac{hc}{\lambda} \\ \Longrightarrow \frac{1}{\lambda} = \frac{1}{\lambda} \\ \Longrightarrow \frac{1}{\lambda} \\ \Longrightarrow \frac{1}{\lambda} = \frac{1}{\lambda} \\ \Longrightarrow \frac{1}{\lambda}$$

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

$$=\frac{9.11\times 10^{-31}\times \left(1.6\times 10^{-19}\right)^4}{8\times \left(8.85\times 10^{-12}\right)^2 \left(6.625\times 10^{-34}\right)^3\times 3\times 10^8}=1.097\times 10^7~\text{m}^{-1}=1.097\times 10^{-3}~\text{Å}^{-1}~\text{(for stationary nucleus)}.$$

If nucleus is not stationary (i.e., mass of nucleus is not much greater than the mass of the revolving particle like electron), then $R = \frac{R_{\infty}}{1+m/M}$ 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
$$\bar{v} = \frac{1}{\lambda} = R \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$$

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 $n_1 = 1 \& n_2 = 2, 3, 4, \dots$

The wavelengths of different members of Lyman series are :

• First member: In this case $n_1 = 1$ and $n_2 = 2$

hence
$$\frac{1}{\lambda} = R \left[\frac{1}{1^2} - \frac{1}{2^2} \right] = \frac{3R}{4} \implies \lambda = \frac{4}{3R} \implies \lambda = \frac{4}{3 \times 10.97 \times 10^6} = 1216 \times 10^{-10} \text{ m} = 1216 \text{Å}$$

• Second member: In this case $n_1 = 1$ and $n_2 = 3$ hence

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

Similarly the wavelength of the other members can be calculated.

• Limiting members: In this case $n_1 = 1$ and $n_2 = \infty$, hence

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

This series lies in ultraviolet region.

- First member: In this case $n_1 = 2$ and $n_2 = 3$, hence

$$\frac{1}{\lambda} = R \left[\frac{1}{2^2} - \frac{1}{3^2} \right] = \frac{5R}{36} \implies \lambda = \frac{36}{5R} \implies \lambda = \frac{36}{5 \times 10.97 \times 10^6} = 6563 \times 10^{-10} m = 6563 \mathring{A}$$

• **Second member**: In this case $n_1 = 2$ and $n_2 = 4$, hence.

$$\frac{1}{\lambda} = R \left[\frac{1}{2^2} - \frac{1}{4^2} \right] = \frac{3R}{16} \implies \lambda = \frac{16}{3R} \implies \lambda = \frac{16}{3 \times 10.97 \times 10^6} = 4861 \times 10^{-10} \text{m} = 4861 \text{Å}$$

• Limiting members: In this case $n_1 = 2$ and $n_2 = \infty$, hence $\frac{1}{\lambda} = R \left[\frac{1}{2^2} - \frac{1}{\infty} \right] = \frac{R}{4} \implies \lambda = \frac{4}{R} = 3646 \text{Å}$

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 $n_1=3 \& n_2=4, 5, 6 \dots \infty$. 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 $n_2 = 4, 5, 6 \dots \infty$

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 $n_1 = 4 \& n_2 = 5, 6, 7, \dots \infty$.

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
$$n_2 = 5, 6, 7 \dots \infty$$

This series lies in infra-red region of spectrum.

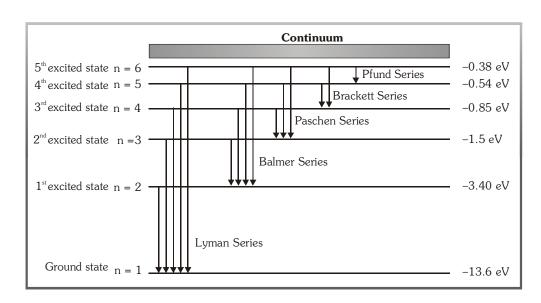
The different wavelengths of this series can be obtained from the formula $\frac{1}{\lambda} = R \left[\frac{1}{5^2} - \frac{1}{n_2^2} \right]$

where
$$n_2 = 6, 7, 8 \dots \infty$$

This series lies in infra-red region of spectrum.

The result are tabulated below

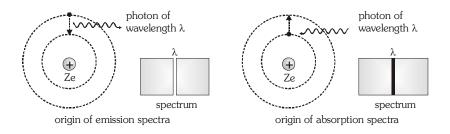
S. No.	Series	Value of n ₁	Value of n,	Position in the
	Observed	1	-	Spectrum
1.	Lyman Series	1	2,3,4∞	Ultra Voilet
2.	Balmer Series	2	3,4,5∞	Visible
3.	Paschen Series	3	4,5,6∞	Infra-red
4.	Brackett Series	4	5,6,7∞	Infra-red
5.	Pfund Series	5	6,7,8∞	Infra–red



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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 :

$$E_{n_2} - E_{n_1} = \frac{me^4}{8\epsilon_0^2 h^2} \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2$$

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

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

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

Putting n=2 in equation (i) we get

$$Z^2 = \frac{204 \times 16}{13.6 \times 15} \implies Z = 4 : E_n = -13.6 \frac{Z^2}{n^2} \implies E_1 = -13.6 \times \frac{4^2}{1^2} = -217.6 \text{ eV} = \text{ground state energy}$$

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 = $5.3 \times 10^{-11} \text{ m}$, Velocity of light = $3 \times 10^8 \text{ m/s}$. Planck's constant = $6.6 \times 10^{-34} \text{ J-s}$]
- **Sol.** The energy required to excite the electron from n_1 to n_2 orbit revolving around the nucleus with

$$\text{charge +Ze is given by } E_{n_2} - E_{n_1} = \frac{me^4}{8\epsilon_0^2h^2} \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_1} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_1} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_1} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_1} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_1} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_1} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_1} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_2} - E_{n_2} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_2} - E_{n_2} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_2} - E_{n_2} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_2} - E_{n_2} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_2} - E_{n_2} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_2} - E_{n_2} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_2} - E_{n_2} - E_{n_2} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Bigg] Z^2 \\ \implies E_{n_2} - E_{n_2} - E_{n_2} - E_{n_2} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Big] Z^2 \\ \implies E_{n_2} - E_{n_2} - E_{n_2} - E_{n_2} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Big] Z^2 \\ \implies E_{n_2} - E_{n_2} - E_{n_2} - E_{n_2} = Z^2 \times \big(13.6\big) \Bigg[\frac{1}{n_1^2} - \frac{1}{n_2^2} \Big] Z^2 \\ \implies E_{n_2} - E_{$$

(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

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

(iv) K.E. =
$$\frac{1}{2}$$
mv₁² = $\frac{1}{2}$ × $\frac{Ze^2}{4\pi g}$ = 543.4 × 10⁻¹⁹ J

P.E. =
$$-2 \times K.E. = -1086.8 \times 10^{-19} \text{ J}$$

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

The radius r_1 of the first Bohr orbit is given by

$$r_{_{1}} = \frac{\epsilon_{_{0}}h^{^{2}}}{\pi me^{^{2}}} \cdot \frac{1}{Z} = \frac{0.53 \times 10^{^{-10}}}{5} \left(\because \frac{\epsilon_{_{0}}h^{^{2}}}{\pi me^{^{2}}} = 0.53 \times 10^{^{-10}} m \right) \\ = 1.106 \times 10^{^{-10}} \, m = 0.106 \, \mathring{A}$$

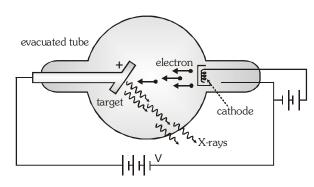
Physical quantity	Formula	Ratio Formulae of hydrogen atom
Radius of Bohr orbit (r _n)	$r_n = \frac{n^2 h^2}{4\pi^2 mkZe^2}$; $r_n = 0.53 \frac{n^2}{Z} \text{ Å}$	r_1 : r_2 : r_3 r_n = 1:4:9 n^2
Velocity of electron in n th Bohr orbit (v _n)	$v_n = \frac{2\pi kZe^2}{nh}$; $v_n = 2.2 \times 10^6 \frac{Z}{n}$	$v_1:v_2:v_3v_n = 1:\frac{1}{2}:\frac{1}{3}\frac{1}{n}$
Momentum of electron (p _n)	$p_n = \frac{2\pi m k e^2 z}{nh}$; $p_n \propto \frac{Z}{n}$	$p_1: p_2: p_3 p_n = 1: \frac{1}{2}: \frac{1}{3} \frac{1}{n}$
Angular velocity of electron(ω_n)	$\omega_{n} = \frac{8\pi^{3}k^{2}Z^{2}mc^{4}}{n^{3}h^{3}}; \ \omega_{n} \propto \frac{Z^{2}}{n^{3}}$	$\omega_1:\omega_2:\omega_3\omega_n = 1:\frac{1}{8}:\frac{1}{27}\frac{1}{n^3}$
Time Period of electron (T _n)	$T_n = \frac{n^3 h^3}{4\pi^2 k^2 Z^2 m e^4} ; T_n \propto \frac{n^3}{Z^2}$	$T_1:T_2:T_3T_n = 1:8:27::n^3$
Frequency (f _n)	$f_n = \frac{4\pi^2 k^2 Z^2 e^4 m}{n^3 h^3}; f_n \propto \frac{Z^2}{n^3}$	$f_1: f_2: f_3 \dots f_n = 1: \frac{1}{8}: \frac{1}{27} \dots \frac{1}{n^3}$
Orbital current (I _n)	$I_n = \frac{4\pi^2 k^2 Z^2 m e^5}{n^3 h^3}; I_n \propto \frac{Z^2}{n^3}$	$I_1: I_2: I_3 \dots I_n = 1: \frac{1}{8}: \frac{1}{27} \dots \frac{1}{n^3}$
Angular momentum (J _n)	$J_n = \frac{nh}{2\pi} \; ; J_n \propto n$	$J_1:J_2:J_3J_n = 1:2:3n$
Centripetal acceleration (a _n)	$a_n = \frac{16\pi^4 k^3 Z^3 me^6}{n^4 h^4}; a_n \propto \frac{Z^3}{n^4}$	$a_1: a_2: a_3 a_n = 1: \frac{1}{16}: \frac{1}{81} \frac{1}{n^4}$
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)	$E_n = \frac{-RchZ^2}{n^2} ; E_n \propto \frac{Z^2}{n^2}$	$E_1: E_2: E_3 \dots E_n = 1: \frac{1}{4}: \frac{1}{9} \dots \frac{1}{n^2}$

X-RAYS

ROENTGEN EXPERIMENT

ALLEN

Roentgen discovered X-ray. While performing experiment on electric discharge tube Roentgen observed that when pressure inside the tube is 10⁻³mm 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.

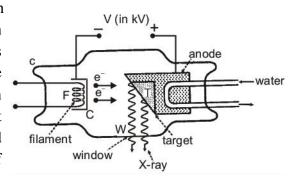


To Produce X-ray Three Things are Required

- (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.

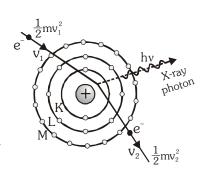


Characteristics of target

- (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.



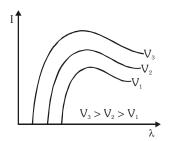
Loss in Kinetic Energy

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

(In first collision, heat = 0)

$$\frac{1}{2} mv^2 = hv_{max} \qquad ...(i)$$

$$\frac{1}{2}$$
 mv² = eV ...(ii) [here V is applied potential]

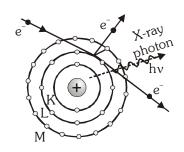


$$from (i) \ and (ii) \ h\nu_{max} = eV \Rightarrow \ \frac{hc}{\lambda_{min}} = eV \Rightarrow \ \lambda_{min} = \frac{12400}{V} \times \ volt = \frac{12400}{V} \times 10^{-10} \ m \times \ volt$$

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.



$$n_1 = 1$$
,

$$n_2 = 2, 3, 4.....K$$
 series

$$n = 2$$

$$n_1 = 2$$
, $n_2 = 3, 4, 5$L series

$$n_1 = 3$$
,

$$n_2 = 4, 5, 6.....M$$
 series

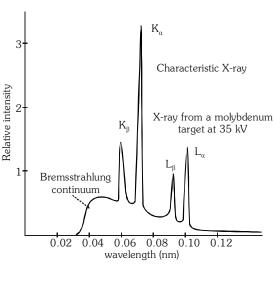
First line of series = α

Second line of series = β

O Ν $N_{\alpha}N_{\beta}$ N series 3 M $M_{\alpha}M_{\beta}M_{\gamma}$ M series $L_{\alpha}L_{\beta}\,L_{\gamma}$ L series

Third line of series = γ

Tra	ansition	Wave- length	Energy	Energy difference	Wavelength	
L	\rightarrow K	$\lambda_{_{Klpha}}$	$h\nu_{_{K\alpha}}$	$-(E_K - E_L)$	$\lambda_{K\alpha} = \frac{hc}{(E_K - E_L)}$	3
(2	→ 1)			$=hv_{_{K\alpha}}$	$= \frac{12400}{(E_K - E_L)} \text{ eVÅ}$	tensity 5
M	$I \to K$	$\lambda_{_{K\beta}}$	$h\nu_{_{K\beta}}$	$-(E_K - E_M)$	$\lambda_{K\beta} = \frac{hc}{(E_K - E_M)}$	Relative intensity
(3	→ 1)			$=hv_{K\beta}$	$= \frac{12400}{(E_K - E_M)} \text{ eVÅ}$	1
M	$I \to L$	$\lambda^{}_{L\alpha}$	$h\nu_{_{L\alpha}}$	$-(E_L - E_M)$	$\lambda_{L\alpha} = \frac{hc}{(E_L - E_M)}$	
(3	→ 2)			$=hv_{L\alpha}$	$=\frac{12400}{(E_L-E_M)} \text{ eVÅ}$	



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.

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

Z = atomic number of target

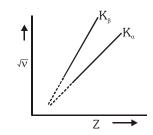
v = frequency of characteristic spectrum

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

a = proportionality constant

From Bohr Model

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



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.	$v = RcZ^{2} \left[\frac{1}{n_{1}^{2}} - \frac{1}{n_{2}^{2}} \right]$	3.	$v = Rc(Z-1)^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$
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
$$\lambda \propto \frac{1}{\frac{1}{n_1^2} - \frac{1}{n_2^2}}$$

When transition is same $\lambda \propto \frac{1}{(Z-b)^2}$

ABSORPTION OF X-RAY

When X-ray passes through x thickness then its intensity $I = I_0 e^{-\mu x}$

 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



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

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.

$$\textbf{Sol.} \quad \mu = \frac{2.303}{x} \quad log \bigg(\frac{I_o}{I}\bigg) \ = \frac{2.303}{10} log_{10} \, 6 = \frac{2.303 \times 0.7781}{10} = 0.1752 / mm$$



DIFFRACTION OF X-RAY

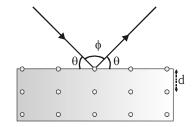
Diffraction of X–ray is possible by crystals because the interatomic spacing in a crystal lattice is order of wavelength of X–rays it was first verified by Lauve.

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

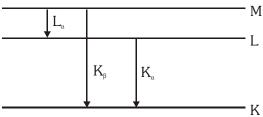
$$\sin \theta = 1, n = 1 \Rightarrow \lambda_{max} = 2d$$

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
$$K_{\alpha}$$
 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 E_{α} X-rays is $E_{L\alpha} = E_M - E_L$
thus $E_{K\beta} = E_{K\alpha} + E_{L\alpha}$ or $V_{K\beta} = V_{K\alpha} + V_{L\alpha}$



EXERCISE (S)

Photoelectric Effect:

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/m², then plot a graph between anode potential and current.a
 - (b) Also draw a graph focar intensity of incident radiation of 2×10^{-5} W/m². [**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.
 - (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?

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 > 1For $0 \le x \le 1$. 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. What is the shortest wavelength present in the Paschen series of spectral lines?

NCERT MP0014

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

NCERT

MP0015

- 15. The total energy of an electron in the first excited state of the hydrogen atom is about $-3.4 \, \text{eV}$.
 - (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

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14.

16. 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**

17. 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 $16 \, \text{eV}$. Estimate the minimum value of V(in kV) such that the electrons will cause ionization in argon atoms by collision .

MP0018

X-Rays

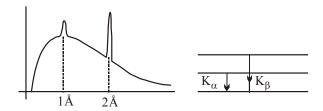
The wavelength of characteristic K_{α} -line emitted by a hydrogen like element is 2.5 Å. Find the wavelength of the K_y-line emitted by the same element (in Å). [Assume the shielding effect to be same as of K_a]

MP0020

19. 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 = 10⁹ eV)

> **NCERT MP0021**

Figure shows K_{α} & K_{β} X-rays along with continuous X-ray. Find the energy of L_{α} X-ray. (Use **20.** hc = 12420 evÅ).



MP0022

21. A graph of \sqrt{v} (where v 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_a line for an element of atomic number 41 is given as $\alpha \times 10^{16}$ Hz. Find the value of α .

EXERCISE (O)

SINGLE CORRECT TYPE QUESTIONS

Photoelectric Effect

- 1. Statement 1: Photoelectric effect establishes quantum nature of light.
 - **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 $\lambda_A = 400$ nm, and that of B is $\lambda_B = 600$ 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

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- 30
- The energy flux of sunlight reaching the surface of the earth is 1.388×10^3 W/m². 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 V

MP0048

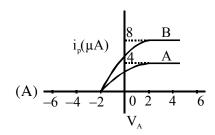
7. Light of frequency 7.21×10^{14} Hz is incident on a metal surface. Electrons with a maximum speed of 6.0×10^5 m/s are ejected from the surface. The threshold frequency for photoemission of electrons is:-

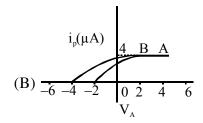
NCERT

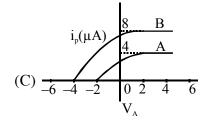
- (A) 4.73×10^{14} Hz
- (B) $4.73 \times 10^{10} \text{ Hz}$
- (C) $2.08 \times 10^{10} \text{ Hz}$
- (D) None of these

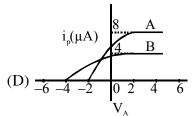
MP0049

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⁻²s⁻¹, saturation current of 4.0 μ A 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:









MP0050

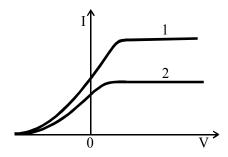
9. Statement-1: When ultraviolet light is incident on a photocell, its stopping potential is V_0 and the maximum kinetic energy of the photoelectrons is K_{max} . When the ultraviolet light is replaced by infrared light, both V_0 and K_{max} increase.

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

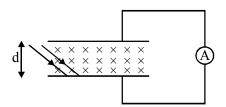
10. A photocathode can be illuminated by the light from two sources, each of which emits monochromatic radiation. The sources are positioned at equal distances from the photocathode. The dependence of the photocurrent on the voltage between the cathode and the anode is depicted by curve 1 for one source 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 emmitted per second
- (D) None of these

MP0052

11. In an experiment on photoelectric effect, the emitter and the collector plates are placed at a separation d and are connected through an ammeter without any cell. A magnetic field B exists parallel to the plates (as shown). The work function of the emitter is ϕ and light incident on it has wavelength λ . Then the minimum value of B for which ammeter registers zero current will be (Take mass of electron as m and charge on it is e)



$$(A) \ \frac{1}{2d} \sqrt{m \left(\frac{hc}{\lambda} - \phi\right)} \quad (B) \ \frac{2}{ed} \sqrt{2m \left(\frac{hc}{\lambda} - \phi\right)} \quad (C) \ \frac{1}{ed} \sqrt{m \left(\frac{hc}{\lambda} - \frac{\phi}{2}\right)} \quad (D) \ \frac{2}{ed} \sqrt{m \left(\frac{2hc}{\lambda} - \phi\right)}$$

(D)
$$\frac{2}{\text{ed}} \sqrt{m \left(\frac{2\text{hc}}{\lambda} - \phi \right)}$$

MP0311

- **12.** A radiation of energy E falls normally on a perfectly reflecting surface. The momentum transferred to the surface is-
 - (A) E/c
- (B) 2E/c
- (C) Ec
- (D) E/c^2

MP0053

Wave Nature oF Matter

- **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.

	,			
14.	-	at rest decays into two paroglie wavelengths of the		3m having non-zero velocities
	$(A) \frac{1}{2}$	(B) $\frac{1}{4}$	(C) 2	(D) 1
				MP0059
15.	A free particle with in	nitial kinetic energy E an	d de-broglie wavelengt	th λ enters a region in which i
	has potential energy U	J. What is the particle's r	new de-Broglie waveler	ngth?
	(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
16.	A proton has kinetic	energy $E = 100 \text{ keV}$ wh	hich is equal to that of	a photon. The wavelength of
	photon is λ_2 and that	t of proton is λ_1 . The ra	tio of λ_1 / λ_2 is proport	ional to [JEE-2004 (Scr.)]
	$(A) E^2$	(B) $E^{1/2}$	(C) E^{-1}	(D) $E^{-1/2}$
				MP0312
17.	Proton, deutron and α	particles are accelerated	through the same poter	ntial difference. Then the ratio
	of their de-Broglie wa	evelength as		
	(A) $1:\sqrt{2}:1$	(B) 1:1:1	(C) $1:2:2\sqrt{2}$	(D) $2\sqrt{2}:2:1$
				MP0061
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Statement-1: An electron and a proton are accelerated through the same potential difference. The 18. 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

- **19.** 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

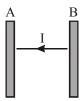
- **20.** After absorbing a slowly moving neutron of mass m_N (momentum ~0) a nucleus of mass M breaks into two nuclei of masses m_1 and $3m_1(4m_1 = M + m_N)$, respectively. If the de Broglie wavelength of the nucleus with mass m_1 is λ , then de-Broglie wavelength of the other nucleus will be :-
 - (A) 9 λ
- (B) 3λ
- (C) $\frac{\lambda}{3}$
- (D) λ

MP0064

- 21. A laser gun of power 3 mW and mass 50 gm emits photons of wavelength 500 nm. It is in gravity free space and emits for one hour. Find the distance covered by gun due to recoil in this one hour (approx.):-
 - (A) 1.3 mm
- (B) $2.1 \, \mu m$
- (C) 1.1 cm
- (D) $8.5 \, \text{mm}$

MP0313

22. 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) $\frac{1.5 \text{ I}}{c}$
- (B) $\frac{I}{c}$
- (C) $\frac{3I}{2c}$
- (D) $\frac{3I}{c}$

MP0065

Bohr's Theory

- 23. The de-Broglie wavelength of an electron in the first Bohr orbit is
 - (A) equal to the circumference of first orbit
 - (B) equal to $\frac{1}{2}$ × (circumference of first orbit)
 - (C) equal to $\frac{1}{4}$ × (circumference of first orbit)
 - (D) equal to $\frac{3}{4}$ × (circumference of first orbit)

MP0068

24. 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

25. **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

- **26.** If the binding energy of the electron in a hydrogen atom is 13.6 eV, the energy required to remove the electron from the first excited state of Li²⁺ is-[AIEEE - 2003]
 - (A) 30.6 eV
- (B) 13.6 eV
- (C) 3.4 eV
- (D) 122.4 eV

MP0071

- In the spectrum of single ionised helium, the wavelength of a line observed is almost the same as the 27. 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

- 28. 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

- 29. According to Bohr model, magnetic field at the centre (at the nucleus) of a hydrogen atom due to the motion of the electron in nth orbit is proportional to
 - (A) $1/n^3$
- (B) $1/n^5$
- (C) n^5
- (D) n^3

MP0075

- A photon of 10.2 eV energy collides with a hydrogen atom in ground state inelastically. After few **30.** 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

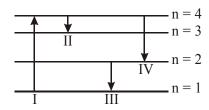
31. The maximum number of emission lines for atomic hydrogen that you would expect to see with naked eye if the only electronic levels involved are those shown in the figure, is

(A)6

(B) 5

- (C) 21
- $(D) \infty$

32. 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

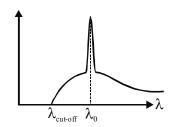
(C) I

(D) II

MP0079

X-Rays

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



Reasoning (**R**): $\lambda_{\text{cut-off}}$ 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

34. 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

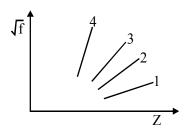
(C) 20000 W

(D) 20 W

MP0082

- **35.** Choose the **INCORRECT** statement.
 - (A) Cut-off wavelength of X-rays is independent of filament voltage.
 - (B) Presence of K_a -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.

The given graph shows the variation of \sqrt{f} vs Z for characteristics X-rays. Lines 1, 2, 3, 4 shown in **36.** 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

- 37. 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

 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

39. The K,L and M energy levels of platinum lie roughly at 78, 12 and 3 keV respectively. The ratio of wavelength of $K_{_{\alpha}}$ line to that of $K_{_{\beta}}$ line in X-ray spectrum is-

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

(D) $\frac{25}{22}$

MP0087

- 40. White X-rays are called "White" because:
 - (A) they are produced most abundantly in X-ray tubes
 - (B) they are electromagnetic waves and hence have a nature similar to white light.
 - (C) they can be converted to visible light using coated screens, and they affect photographic plates, just like white light.
 - (D) they have a continuous range of wavelengths.

MP0314

- 41. 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

MP0092

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42. 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 43.** 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** 44. 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

EXERCISE (JM)

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

1. 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

2. If a source of power 4kW produces 10²⁰ 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

3. 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

4. This question has Statementn-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 explanation of 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

- 5. 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

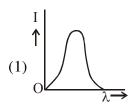
(2)2

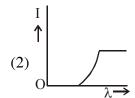
(3)3

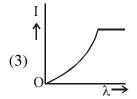
(4)5

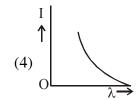
MP0154

6. 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

- 7. 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) $\frac{1}{n^{\frac{3}{2}}}$
- $(4) \frac{1}{n^3}$

MP0156

8. Hydrogen $(_1H^1)$, Deuterium $(_1H^2)$, singly ionised Helium $(_2He^4)^+$ and doubly ionised lithium $(_3Li^6)^{+}$ all have one electron around the nucleus. Consider an electron transition from n=2 to n=1. If the wave lengths of emitted radiation are λ_1 , λ_2 , λ_3 and λ_4 respectively then approximately which one of the following is **correct**? [JEE-Mains - 2014]

$$(1) \lambda_1 = \lambda_2 = 4\lambda_3 = 9\lambda_4$$

(2)
$$\lambda_1 = 2\lambda_2 = 3\lambda_3 = 4\lambda_4$$

$$(3) \ 4\lambda_1 = 2\lambda_2 = 2\lambda_3 = \lambda_4$$

$$(4) \lambda_1 = 2\lambda_2 = 2\lambda_3 = \lambda_4$$

MP0315

- 9. The radiation corresponding to $3 \rightarrow 2$ transition of hydrogen atom falls on a metal surface to produce photoelectrons. These electrons are made to enter a magnetic field of 3×10^{-4} T. If the radius of the largest circular path followed by these electrons is 10.0 mm, the work function of the metal is close to:
 [JEE-Mains 2014]
 - (1) 0.8 eV
- (2) 1.6 eV
- (3) 1.8 eV
- (4) 1.1 eV

MP0316

- **10.** 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

11. 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

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

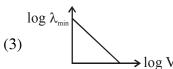
 $(1) = v \left(\frac{3}{5}\right)^{1/2} \qquad (2) > v \left(\frac{4}{3}\right)^{1/2} \qquad (3) < v \left(\frac{4}{3}\right)^{1/2} \qquad (4) = v \left(\frac{4}{3}\right)^{1/2}$

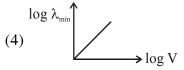
MP0159

An electron beam is accelerated by a potential difference V to hit a metallic target to produce **13.** 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]

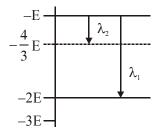
(1)





MP0160

Some energy levels of a molecule are shown in the figure. The ratio of the wavelengths $r = \lambda_1/\lambda_2$, is 14. given by: [JEE Main-2017]



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

$$(1) \frac{\lambda_{A}}{\lambda_{B}} = \frac{2}{3}$$

$$(2) \frac{\lambda_{A}}{\lambda_{B}} = \frac{1}{2} \qquad (3) \frac{\lambda_{A}}{\lambda_{B}} = \frac{1}{3}$$

$$(3) \frac{\lambda_{A}}{\lambda_{B}} = \frac{1}{3}$$

$$(4) \frac{\lambda_{A}}{\lambda_{B}} = 2$$

MP0162

If the series limit frequency of the Lyman series is v_L, then the series limit frequency of the Pfund **16.** series is: [**JEE Main-2018**]

$$(1) 16 v_L$$

$$(2) v_{\rm I} / 16$$

$$(3) v_{\rm I}/25$$

$$(4)\ 25\ v_{\rm T}$$

MP0163

17. A nucleus A, with a finite de-broglie wavelength λ_A , undergoes spontaneous fission into two nuclei B and C of equal mass. B flies in the same direction as that of A, while C flies in the opposite direction with a velocity equal to half of that of B. The de-Broglie wavelengths λ_B and λ_C of B and C are respectively:-[JEE Main (Online)-2019]

$$(1) 2\lambda_{A}, \lambda_{A}$$

$$(2) \lambda_A, 2\lambda_A$$

$$(3) \lambda_A, \frac{\lambda_A}{2}$$

$$(4) \frac{\lambda_A}{2}, \lambda_A$$

MP0317

Radiation coming from transitions n = 2 to n = 1 of hydrogen atoms fall on He⁺ ions in n = 1 and 18. n = 2 states. The possible transition of helium ions as they absorb energy from the radiation is:

[JEE Main (Online)-2019]

$$(1) n = 1 \rightarrow n = 4$$

(2)
$$n = 2 \rightarrow n = 4$$

(3)
$$n = 2 \rightarrow n = 5$$

$$(4) n = 2 \rightarrow n = 3$$

MP0318

Two particles move at right angle to each other. Their de-Broglie wavelengths are λ_1 and λ_2 respectively. **19.** The particles suffer perfectly inelastic collision. The de-Broglie wavelength λ , of the final particle, is [JEE Main (Online)-2019] given by:

$$(1) \lambda = \frac{\lambda_1 + \lambda_2}{2}$$

(1)
$$\lambda = \frac{\lambda_1 + \lambda_2}{2}$$
 (2)
$$\frac{2}{\lambda} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$$
 (3)
$$\lambda = \sqrt{\lambda_1 \lambda_2}$$

$$(3) \lambda = \sqrt{\lambda_1 \lambda_2}$$

(4)
$$\frac{1}{\lambda^2} = \frac{1}{\lambda_1^2} + \frac{1}{\lambda_2^2}$$

MP0319

20. A particle 'P' is formed due to a completely inelastic collision of particles 'x' and 'y' having de-Broglie wavelengths ' λ_x ' and ' λ_y ' respectively. If x and y were moving in opposite directions, then the de-Broglie wavelength of 'P' is :-[JEE Main (Online)-2019]

(1)
$$\lambda_x + \lambda_y$$

$$(2) \frac{\lambda_x \lambda_y}{\lambda_x + \lambda_y}$$

$$(2) \frac{\lambda_x \lambda_y}{\lambda_x + \lambda_y} \qquad (3) \frac{\lambda_x \lambda_y}{|\lambda_x - \lambda_y|}$$

(4)
$$\lambda_{x} - \lambda_{y}$$

MP0320

21. 50 W/m² energy density of sunlight is normally incident on the surface of a solar panel. Some part of incident energy (25%) is reflected from the surface and the rest is absorbed. The force exerted on 1m² surface area will be close to ($c = 3 \times 10^8$ m/s):-[JEE Main (Online)-2019]

(1)
$$15 \times 10^{-8}$$
 N

$$(2) 35 \times 10^{-8} \text{ N}$$

$$(3)\ 10 \times 10^{-8}\ N$$

$$(4) 20 \times 10^{-8} \text{ N}$$

- 22. A He⁺ ion is in its first excited state. Its ionization energy is:-
- [JEE Main (Online)-2019]

- (1) 6.04 eV
- (2) 13.60 eV
- (3) 54.40 eV
- (4) 48.36 eV

MP0322

- 23. The electric field of light wave is given as $\vec{E} = 10^{-3} \cos \left(\frac{2\pi x}{5 \times 10^{-7}} 2\pi \times 6 \times 10^{14} \, t \right) \hat{x} \frac{N}{C}$. This light falls on
 - a metal plate of work function 2eV. The stopping potential of the photo-electrons is:

Given, E (in eV) = $\frac{12375}{\lambda(\text{in Å})}$

[JEE Main (Online)-2019]

- (1) 0.48 V
- (2) 2.0 V
- (3) 2.48 V
- (4) 0.72 V

MP0323

- **24.** Taking the wavelength of first Balmer line in hydrogen spectrum (n = 3 to n = 2) as 660 nm, the wavelength of the 2^{nd} Balmer line (n = 4 to n = 2) will be : [**JEE Main (Online)-2019**]
 - (1) 889.2 nm
- (2) 642.7 nm
- (3) 488.9 nm
- (4) 388.9 nm

MP0324

- 25. Light is incident normally on a completely absorbing surface with an energy flux of 25 Wcm⁻². if the surface has an area of 25 cm⁻², the momentum transferred to the surface in 40 min time duration will be: [JEE Main (Online)-2019]
 - $(1) 5.0 \times 10^{-3} \text{ Ns}$
- $(2) 3.5 \times 10^{-6} \text{ Ns}$
- $(3) 1.4 \times 10^{-6} \text{ Ns}$
- $(4) 6.3 \times 10^{-4} \text{ Ns}$

MP0325

- **26.** A 2 mW laser operates at a wavelength of 500 nm. The number of photons that will be emitted per second is : [JEE Main (Online)-2019]
 - [Given Planck's constant h = 6.6×10^{-34} Js, speed of light c = 3.0×10^8 m/s]
 - $(1) 2 \times 10^{16}$
- (2) 1.5×10^{16}
- $(3) 5 \times 10^{15}$
- (4) 1×10^{16}

MP0326

27. In Li⁺⁺, electron in first Bohr orbit is excited to a level by a radiation of wavelength λ . when the ion gets deexcited to the ground state in all possible ways (including intermediate emissions), a total of six spectral lines are observed. What is the value of λ ?

(Given : $h = 6.63 \times 10^{-34} \text{ Js}$; $c = 3 \times 10^8 \text{ ms}^{-1}$)

[JEE Main (Online)-2019]

- (1) 9.4 nm
- (2) 12.3 nm
- (3) 10.8 nm
- (4) 11.4 nm

MP0327

- **28.** A proton, an electron, and a Helium nucleus, have the same energy. They are in circular orbits in a plane due to magnetic field perpendicualr to the plane. Let r_p , r_e and r_{He} be their respective radii, then,
 - [JEE Main (Online)-2019]

- $(1) r_{e} > r_{p} > r_{He}$
- $(2) r_e < r_n < r_{He}$
- (3) $r_e < r_p = r_{He}$
- $(4) r_e > r_n = r_{He}$

MP0328

29. In a photoelectric effect experiment the threshold wavelength of the light is 380 nm. If the wavelentgh of incident light is 260 nm, the maximum kinetic energy of emitted electrons will be: Given E (in eV)

$$= \frac{1237}{\lambda (\text{in nm})}$$

[JEE Main (Online)-2019]

- (1) 1.5 eV
- (2) 4.5 eV
- (3) 15.1 eV
- (4) 3.0 eV

30. The electron in a hydrogen atom first jumps from the third excited state to the second excited state and subsequently to the first excited state. The ratio of the respective wavelengths, λ_1/λ_2 , of the photons emitted in this process is : [JEE Main (Online)-2019]
(1) 9/7 (2) 7/5 (3) 27/5 (4) 20/7

MP0330

31. Consider an electron in a hydrogen atom, revolving in its second excited state (having radius 4.65Å). The de-Broglie wavelength of this electron is: [JEE Main (Online)-2019]

(1) 12.9 Å

(2) 3.5 Å

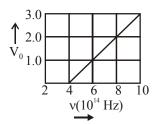
(3) 9.7 Å

(4) 6.6 Å

MP0331

32. The stopping potential V_0 (in volt) as a function of frequency (v) for a sodium emitter, is shown in the figure. The work function of sodium, from the data plotted in the figure, will be:

(Given : Planck's constant (h) = 6.63×10^{-34} Js, electron charge e = 1.6×10^{-19} C)[JEE Main (Online)-2019]



(1) 1.95 eV

(2) 1.82 eV

(3) 1.66 eV

(4) 2.12 eV

MP0332

33. An excited He⁺ ion emits two photons in succession, with wavelengths 108.5 nm and 30.4 nm, in making a transition to ground state. The quantum number n, corresponding to its initial excited

state is (for photon of wavelength λ , energy $E = \frac{1240 \,\text{eV}}{\lambda (\text{in nm})}$):

[JEE Main (Online)-2019]

(1) n = 5

(2) n = 4

(3) n = 6

(4) n = 7

MP0333

34. The magnetic field associated with a light wave is given, at the origin, by $B = B_0 [\sin(3.14 \times 10^7)\text{ct} + \sin(6.28 \times 10^7)\text{ct}]$. If this light falls on a silver plate having a work function of 4.7 eV, what will be the maximum kinetic energy of the photo electrons?

 $(c = 3 \times 10^8 \text{ms}^{-1}, h = 6.6 \times 10^{-34} \text{J-s})$

[JEE Main (Online)-2019]

(1) 7.72 eV

(2) 8.52 eV

(3) 12.5 eV

(4) 6.82 eV

MP0334

35. Surface of certain metal is first illuminated with light of wavelength $\lambda_1 = 350$ nm and then, by light of wavelength $\lambda_2 = 540$ nm. It is found that the maximum speed of the photo electrons in the two cases differ by a factor of 2. The work function of the metal (in eV) is close to:

(Energir of photon = $\frac{1240}{\lambda(\text{in nm})}$ eV)

[JEE Main (Online)-2019]

(1) 1.8

(2) 1.4

(3) 2.5

(4) 5.6

MP0336

- In a hydrogen like atom, when an electron jumps from the M shell to the L shell, the wavelength **37.** of emitted radiation is λ . If an electron jumps from N-shell to the L-shell, the wavelength of emitted radiation will be :-[JEE Main (Online)-2019]
 - $(1) \frac{27}{20} \lambda$
- $(2) \frac{16}{25} \lambda$
- $(3) \frac{20}{27} \lambda$
- $(4) \frac{25}{16} \lambda$

MP0337

In a photoelectric experiment, the wavelength of the light incident on a metal is changed from 300 38. nm to 400 nm. The decrease in the stopping potential is close to : $\left(\frac{hc}{g} = 1240 \text{ nm} - V\right)$

[JEE Main (Online)-2019]

- (1) 0.5 V
- (2) 1.0 V
- (3) 2.0 V
- (4) 1.5 V

MP0338

A hydrogen atom, initially in the ground state is excited by absorbing a photon of wavelength 980Å. **39.** The radius of the atom in the excited state, it terms of Bohr radius a_0 , will be :

 $(h_c = 12500 \text{ eV} - \text{Å})$

[JEE Main (Online)-2019]

- $(1) 9a_0$
- $(2) 25a_0$
- $(3) 4a_0$
- $(4) 16a_0$

MP0339

- If the deBronglie wavelength of an electron is equal to 10⁻³ times the wavelength of a photon of 40. frequency 6×10^{14} Hz, then the speed of electron is equal to : [JEE Main (Online)-2019] (Speed of light = 3×10^8 m/s, Planck's constant = 6.63×10^{-34} J.s, Mass of electron = 9.1×10^{-31} kg)
 - (1) 1.45×10^6 m/s
- (2) 1.7×10^6 m/s
- (3) 1.8×10^6 m/s
- $(4) 1.1 \times 10^6 \text{ m/s}$

MP0340

- 41. In a Frank-Hertz experiment, an electron of energy 5.6 eV passes through mercury vapour and emerges with an energy 0.7 eV. The minimum wavelength of photons emitted by mercury atoms is close to [JEE Main (Online)-2019]
 - (1) 2020 nm
- (2) 220 nm
- (3) 250 nm
- (4) 1700 nm

MP0341

42. A particle of mass m moves in a circular orbit in a central potential field $U(r) = \frac{1}{2}kr^2$. If Bohr's quantization conditions are applied, radii of possible orbitals and energy levels vary with quantum number n as: [JEE Main (Online)-2019]

$$(1) \; r_n \propto n^2 \; , \; E_n \propto \frac{1}{n^2} \; \; (2) \; r_n \propto \sqrt{n} \; , \\ E_n \propto \frac{1}{n} \quad \; (3) \; r_n \propto n , \; E_n \propto n \qquad (4) \; r_n \propto \sqrt{n} \; , \; E_n \propto n$$

MP0342

43. A particle A of mass 'm' and charge 'q' is accelerated by a potential difference of 50 V. Another particle B of mass '4 m' and charge 'q' is accelerated by a potential difference of 2500 V. The ratio of de-Broglie wavelengths $\frac{\lambda_A}{\lambda_B}$ is close to : [JEE Main (Online)-2019]

(1) 10.00

(2) 14.14

(3) 4.47

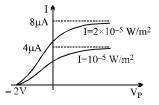
(4) 0.07

MP0343

ANSWER KEY

EXERCISE (S)

- 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 $eV_0 = hv \phi_0$ for both sources. From the data on the first source, $\phi_0 = 1.40$ 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) $4.04 \times 10^{-24} \text{ kg ms}^{-1}$ (b) 0.164 nm
- 7. Ans. (a) $6.95 \times 10^{-25} \text{ J} = 4.34 \,\mu\text{eV}$ (b) $3.78 \times 10^{-28} \,\text{J} = 0.236 \,\text{neV}$
- **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. 820 nm.
- 14. Ans. Lyman series: 103 nm and 122 nm; Balmer series: 656 nm.
- **15. Ans.** (a) +3.4 eV; (b) -6.8 eV; (c) potential energy
- **16. Ans.** 2.56×10^{-13} m; -2.8 keV

- **17. Ans.** 8 **18. Ans.** 2
- **19. 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.
- 20. Ans. 6210 eV 21. Ans. 400

EXERCISE (O)

SINGLE CORRECT TYPE QUESTIONS

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. (B)
13. Ans. (D)	14. Ans. (D)	15. Ans. (A)	16. Ans. (B)	17. Ans. (D)	18. Ans. (A)
19. Ans. (C)	20. Ans. (D)	21. Ans. (A)	22. Ans. (D)	23. Ans. (A)	24. Ans. (A)
25. Ans. (A)	26. Ans. (A)	27. Ans. (A)	28. Ans. (D)	29. Ans. (B)	30. Ans. (A)
					

- 31. Ans. (B) 32. Ans. (D) 33. Ans. (A) 34. Ans. (A) 35. Ans. (D) 36. Ans. (B)
- 37. Ans. (D) 38. Ans. (D) 39. Ans. (D) 40. Ans. (D) 41. Ans. (C) 42. Ans. (D)
- 43. Ans. (C) 44. Ans. (A)

EXERCISE (JM)

1. Ans. (1)	2. Ans. (2)	3. Ans. (1)	4. Ans. (2)	5. Ans. (1)	6. Ans. (4)
7. Ans. (4)	8. Ans. (1)	9. Ans. (4)	10. Ans. (3)	11. Ans. (1)	12. Ans. (2)
40 4 (0)	44 4 74	4 - 4 - 45	4 - 4 - (5)	4- 4 (4)	40 4 (6)

- 13. Ans. (3) 14. Ans. (2) 15. Ans. (4) 16. Ans. (3) 17. Ans. (4) 18. Ans. (2)
- 19. Ans. (4) 20. Ans. (3) 21. Ans. (4) 22. Ans. (2) 23. Ans. (1) 24. Ans. (3)
- 25. Ans. (1) 26. Ans. (3) 27. Ans. (3) 28. Ans. (3) 29. Ans. (1) 30. Ans. (4)
- 31. Ans. (3) 32. Ans. (3) 33. Ans. (1) 34. Ans. (1) 35. Ans. (1) 36. Ans. (4)
- 37. Ans.(3) 38. Ans.(2) 39. Ans.(4) 40. Ans.(1) 41. Ans.(3) 42. Ans.(4)
- 43. Ans. (2)

Important Notes	

Ε