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PHYSICS

Chapter Contents 01

MODERN PHYSICS-1

Important Notes

MODERN PHYSICS-1

KEY CONCEPT

PHOTO ELECTRIC EFFECT

PHOTOELECTRIC EFFECT

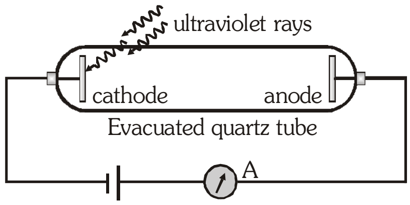
It was discovered by Hertz in 1887. He found that when the negative plate of an electric discharge tube was illuminated with ultraviolet light, the electric discharge took place more readily. Further experiments carried out by Hallwachs confirmed that certain negatively charged particles are emitted,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

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

EXPLANATION OF PHOTOELECTRIC EFFECT

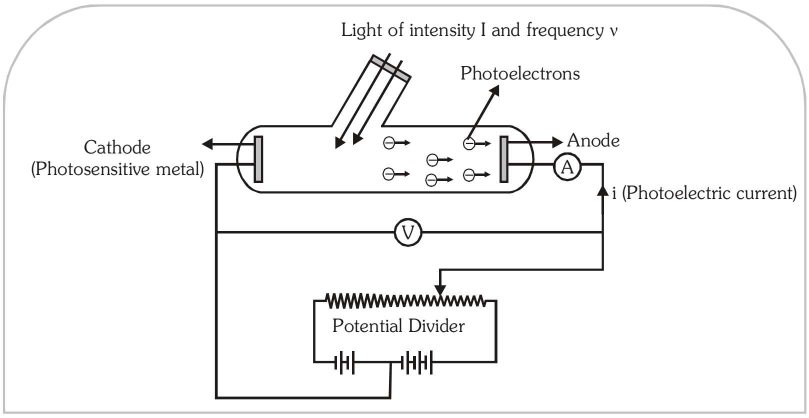
- **On the basis of wave theory** :According to wave theory, light is an electromagnetic radiation consisting of oscillating electric field vectors and magnetic field vectors. When electromagnetic radiations are incident on a metal surface, the free electrons [free electrons means the electrons which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

EXPERIMENTS



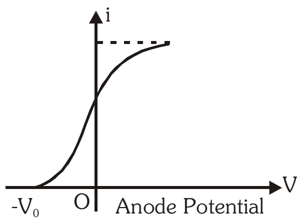
- **Hertz Experiment**
  Hertz observed that when ultraviolet rays are incident on negative plate of electric discharge tube then conduction takes place easily in the tube.
- **Hallwach experiment :** Hallwach observed that if negatively charged Zn plate is illuminated by U.V. light, its negative charge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

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



(i) Variation of photoelectric current with potential difference

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



The main points of observation are :

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

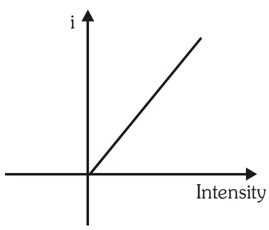
(b) As anode potential is increased, current increases. This implies that different electrons are emitted with different kinetic energies.

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

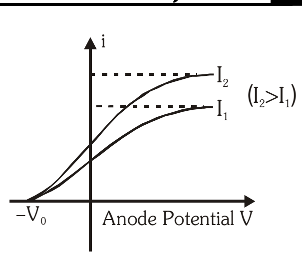
(d) At a certain negative potential, the photoelectric current becomes zero. This is called stopping potential (V_0). Stopping potential is a measure of maximum kinetic energy of the emitted electrons. Let KE_{max} be the maximum kinetic energy of an emitted electron, then $KE_{max} = eV_0$.

(ii) Variation of current with intensity

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



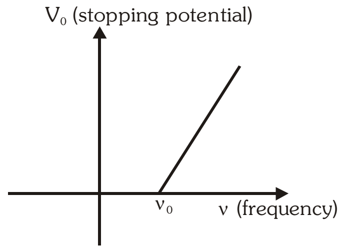
(iii) Effect of intensity on saturation current and stopping potential



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

IMPORTANT POINTS

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

- **Failure of wave theory of light**

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

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

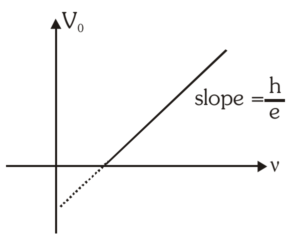
(iii) According to wave theory, if intensity is sufficient then, at each frequency, electron emission is possible. It means there should not be existence of threshold frequency.

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

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

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

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



The remaining energy appears as kinetic energy of the electron.

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

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

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

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

IMPORTANT POINTS

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

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

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

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

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

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

$$\Rightarrow V_0 = \frac{1}{2}\frac{mv_{max}^2}{e} = \frac{hc}{e\lambda} - \frac{\phi}{e} = \frac{12400}{4360} - 1.24 = 1.60 \text{ V} \quad \left[\because \frac{hc}{e} = 12400\times10^{-10}\,\text{V}-\text{m}\right]$$

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

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

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

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

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

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

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

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

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

PHOTON THEORY OF LIGHT

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

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

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

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

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

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

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

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

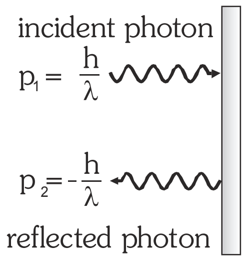
  Intensity $I = \frac{N(h\nu)}{At} = \frac{n(h\nu)}{A}$ ...(ii)

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

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

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

  Let 'N' photons are there in time t,



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

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

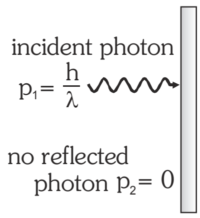
Change in momentum of photons $= p_2 - p_1 = \frac{-2Nh}{\lambda}$

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

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

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

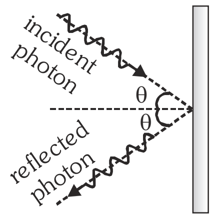
- **Force exerted on perfectly absorbing surface**



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

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

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



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

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

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

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

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

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

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

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

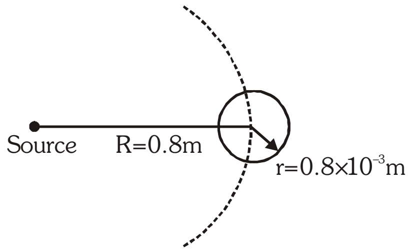
Ex. In a photoelectric setup, a point source of light of power 3.2×10^{-3} W emits monochromatic photons of energy 5.0 eV. The source is located at a distance 0.8 m from the centre of a stationary metallic sphere of work function 3.0 eV and radius 8×10^{-3} m. The efficiency of photoelectron emission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

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

Power of source P = 3.2×10^{-3} W

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

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



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

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

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

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

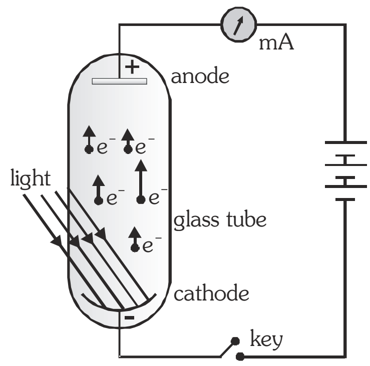
As $KE_{max} = 2.0$ eV $\Rightarrow$ Stopping potential $V_0 = 2V \Rightarrow 2 = \frac{q}{4\pi\varepsilon_0 r} \Rightarrow q = 1.78 \times 10^{-12}$ C

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

PHOTO CELL

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

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



- **Application**

(i) In television camera.

(ii) In automatic door

(iii) Burglar's alarm

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

MATTER WAVES THEORY

DUAL NATURE OF LIGHT

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

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

De-Broglie HYPOTHESIS

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

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

If a particle of mass m moving with velocity v

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

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

The smallest wavelength whose measurement is possible is that of γ – rays ($\lambda \simeq 10^{-5}$ 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** $m_e = 9.1 \times 10^{-31}$ kg, $q = 1.6 \times 10^{-19}$ C, $h = 6.62 \times 10^{-34}$ J–s

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

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

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

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

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

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

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

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

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

DE BROGLIE WAVELENGTH ASSOCIATED WITH UNCHARGED PARTICLES

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

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

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

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

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

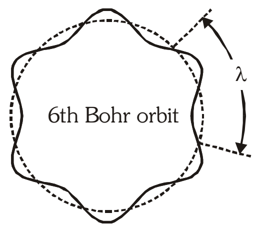
Kinetic energy of the particle in terms of its wavelength $E = \frac{h^2}{2m\lambda^2} = \frac{h^2}{2m\lambda^2 \times 1.6 \times 10^{-19}}$ eV

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

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

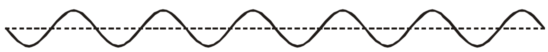
EXPLANATION OF BOHR QUANTIZATION CONDITION

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



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

This is the Bohr quantizations condition.


equivalent straightened orbit

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

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

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

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

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

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

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

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

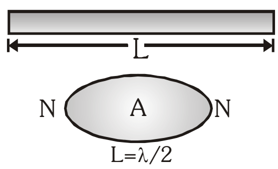
Ex. A particle of mass m is confined to a narrow tube of length L.

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

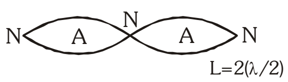
(b) Calculate the corresponding particle momenta, and

(c) Calculate the corresponding energies.

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

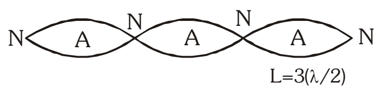


Few of the possible resonance forms are as follows : $\lambda_n = \frac{2L}{n}$, n=1,2,3.....

(b) 

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

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



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

ATOMIC STRUCTURE

VARIOUS MODELS FOR STRUCTURE OF ATOM

- **Dalton's Theory**

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

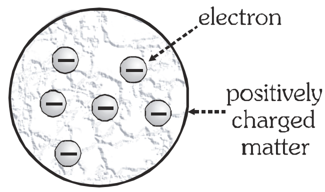
  All atoms of same element are identical physically as well as chemically, whereas atoms of different elements are different in properties.

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

  The atom is stable and electrically neutral.

- **Thomson's Atom Model**

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



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

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

- **Shortcomings of Thomson's model**

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

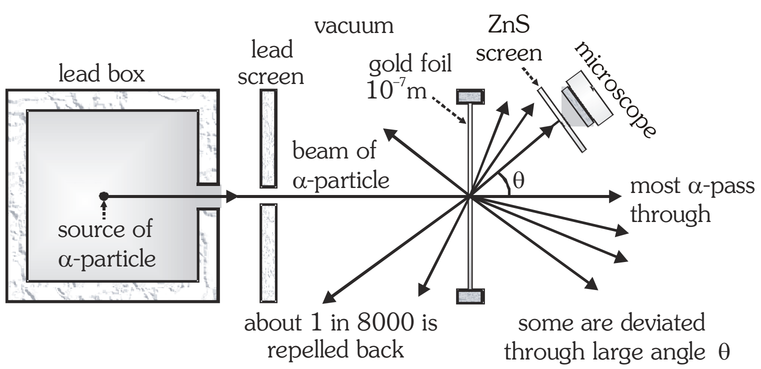
  (ii) Scattering of α–particles cannot be explained with the help of this model

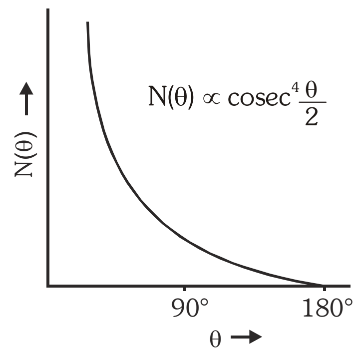
  (iii) Angular frequency of electron in n^{th} orbit $\omega_n = \dfrac{8\pi^2k^2Z^2e^4m}{n^3h^3} \Rightarrow \omega_n \propto \dfrac{Z^2m}{n^3}$

RUTHERFORD ATOM MODEL

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

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





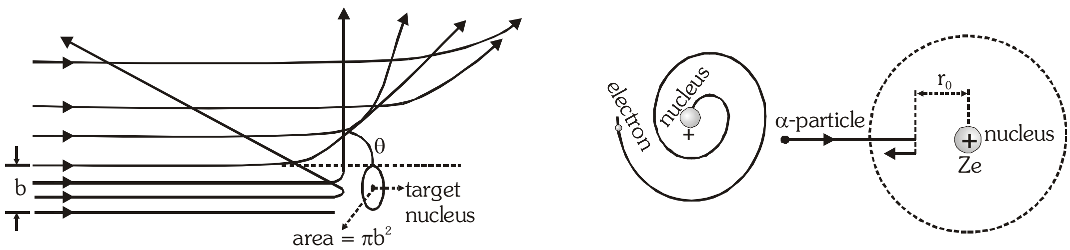
- Most of the α – particles went straight through the gold foil and produced flashes on the screen as if there were nothing inside gold foil. Thus the atom is hollow.
- Few particles collided with the atoms of the foil which have scattered or deflected through considerable large angles. Few particles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

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

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

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

n	=	Number of target atom per m^3
t	=	Thickness of target
Ze	=	Charge on the target nucleus
2e	=	Charge on α – particle
r	=	Distance of the screen from target
v_0	=	Velocity of α – particles at nearer distance of approach the size of a nucleus or the distance of nearer approach is given by.



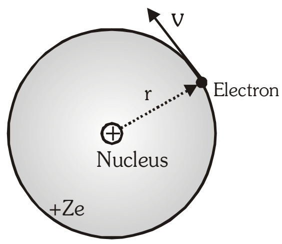
$$r_0 = \frac{1}{4\pi\varepsilon_0} \times \frac{(2Ze)^2}{\left[\frac{1}{2}mv_0^2\right]} = \frac{1}{4\pi\epsilon_0}\frac{(2Ze)^2}{E_K}$$ where E_K = K.E. of α–particle

Bohr's Atomic Model

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

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

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



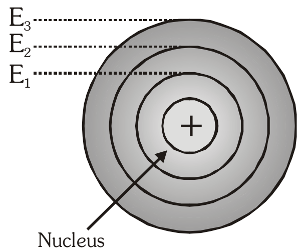
ε_0 =Absolute permittivity of free space = $8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$
m = Mass of electron
v = Velocity (linear) of electron
r = Radius of the orbit in which electron is revolving.
Z = Atomic number of hydrogen like atom.

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

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

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

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



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

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

MATHEMATICAL ANALYSIS OF BOHR'S THEORY

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

We get the following results.

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

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

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

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

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

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

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

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

3. Total energy of electron in nth orbit :

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

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

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

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

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

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

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

5. Frequency of revolution in nth orbit :

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

6. Wavelength of photon

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

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

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

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

SPECTRAL SERIES OF HYDROGEN ATOM

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

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

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

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

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

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

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

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

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

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

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

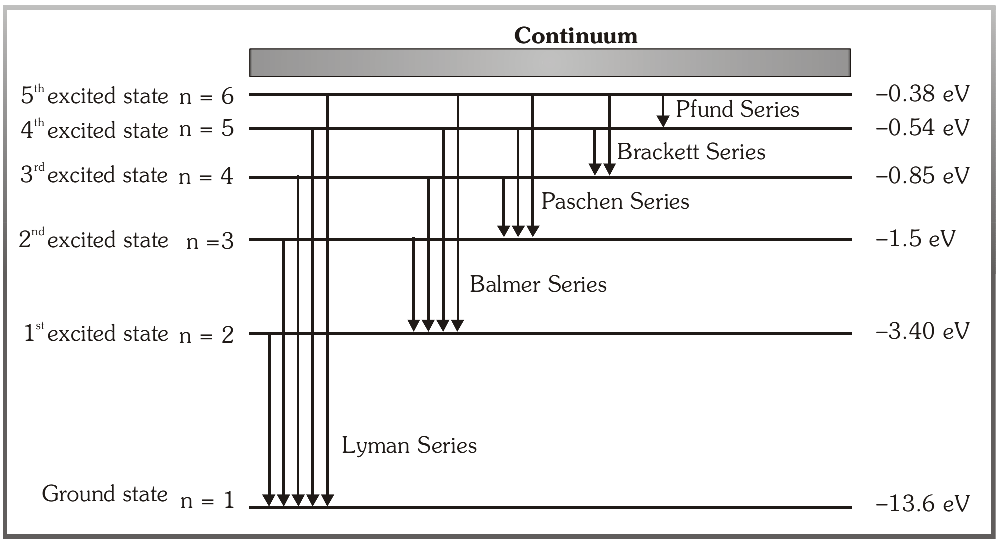
  $\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{4^2}\right] = \frac{3R}{16} \Rightarrow \lambda = \frac{16}{3R} \Rightarrow \lambda = \frac{16}{3 \times 10.97 \times 10^6} = 4861 \times 10^{-10}\text{m} = 4861\text{Å}$
- **Limiting members**: In this case $n_1 = 2$ and $n_2 = \infty$, hence $\frac{1}{\lambda}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

  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 $n_1=3$ & $n_2= 4, 5, 6 ....\infty$. 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 $n_2 = 4, 5, 6 ....\infty$
  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 $n_1 = 4$ & $n_2 = 5, 6, 7, ...\infty$.
  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 $n_2 = 5, 6, 7 ....\infty$
  This series lies in infra–red region of spectrum.
- **Pfund series :** The series consist of all wavelengths which are emitted when an electron jumps from an outer orbit to the fifth orbit i. e., the electron jumps to O orbit give right to Pfund series. Here $n_1 = 5$ and $n_2 = 6, 7, 8 ....\infty$.
  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 $n_2 = 6, 7, 8 ....\infty$
  This series lies in infra–red region of spectrum.

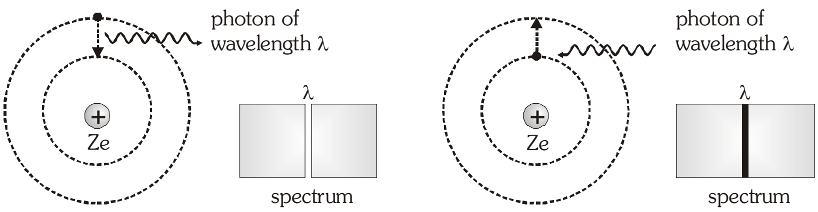
The result are tabulated below

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



EXCITATION AND IONISATION OF ATOMS

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



origin of emission spectra origin of absorption spectra

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

SUCCESSES AND LIMITATIONS

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

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

- The spectral lines of hydrogen atom are not single lines but each one is a collection of several closely spaced lines.
- The structure of multielectron atoms is not explained.

- No explanation for using the principles of quantization of angular momentum.
- No explanation for Zeeman effect. If a substance which gives a line emission spectrum is placed in a magnetic field, the lines of the spectrum get splitted up into a number of closely spaced lines. This phenomenon is known as Zeeman effect.

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

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

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

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

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

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

Putting n=2 in equation (i) we get

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

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 = 5.3×10^{-11} m, Velocity of light = 3×10^8 m/s. Planck's constant = 6.6×10^{-34} J–s]

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

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

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

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

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

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

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

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

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

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

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

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

The radius r_1 of the first Bohr orbit is given by

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

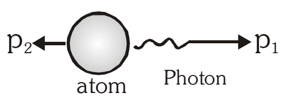
Ex. An isolated hydrogen atom emits a photon of 10.2 eV.

(i) Determine the momentum of photon emitted (ii) Calculate the recoil momentum of the atom

(iii) Find the kinetic energy of the recoil atom [Mass of proton= $m_p = 1.67 \times 10^{-27}$ kg]

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

(ii) Applying the momentum conservation



$p_2 = p_1 = 5.44 \times 10^{-27}$ kg–m/s

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

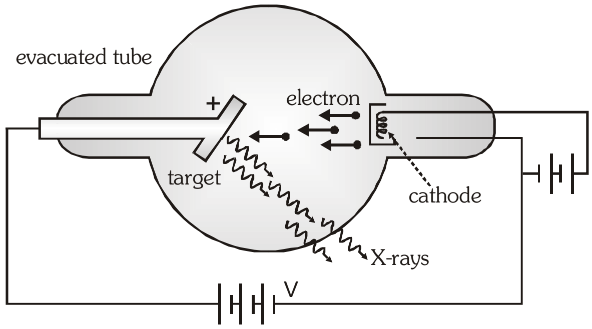
Substituting the value of the momentum of atom, we get $K = \frac{\left(5.44\times 10^{-27}\right)^2}{2\times 1.67\times 10^{-27}} = 8.86 \times 10^{-27}$J

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

X–RAYS

ROENTGEN EXPERIMENT

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



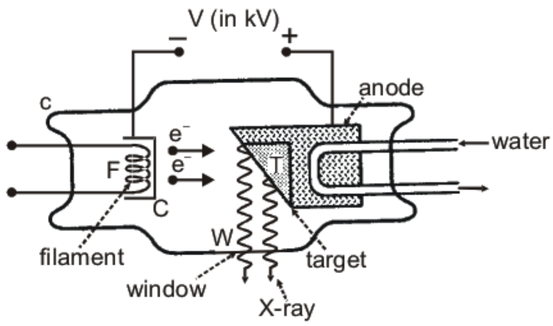
To Produce X–ray Three Things are Required

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

(iii) Target on which these high speed electron strike

COOLIDGE METHOD

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



Characteristics of target

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

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

(c) High thermal conductivity to remove the heat produced

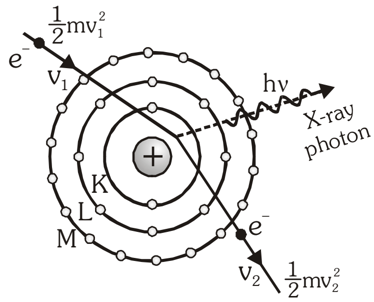
(d) Tantalum, platinum, molybdenum and tungsten serve as target materials

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

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

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

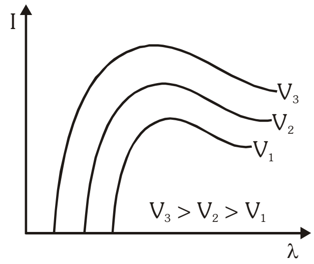
- **Continuous spectrum of X–ray** : When high speed electron collides from the atom of target and passes close to the nucleus.There is coulomb attractive force due to this electron is deaccelerated i.e. energy is decreased. The loss of energy during deacceleration is emitted in the form of X–rays. X–ray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



- **Loss in Kinetic Energy**

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

(In first collision, heat = 0)



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

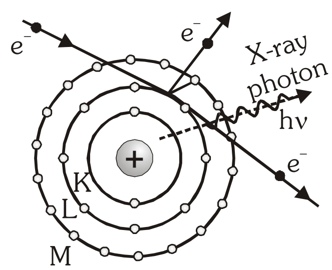
$\frac{1}{2}mv^2 = eV$ ...(ii) [here V is applied potential]

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

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

- **Characteristic Spectrum of X–ray**

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



From Bohr Model

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

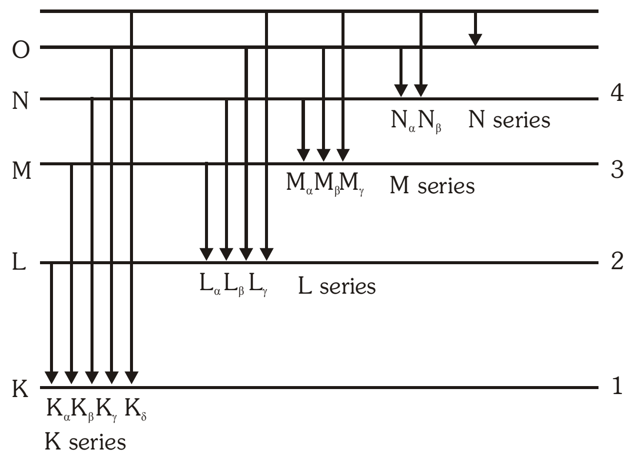
$n_1 = 2$, $n_2 = 3, 4, 5$.......L series

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

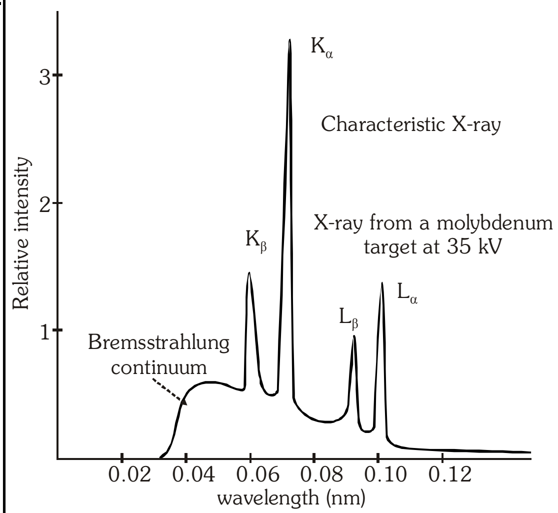
First line of series = α

Second line of series = β

Third line of series = γ



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



MOSELEY'S LAW

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

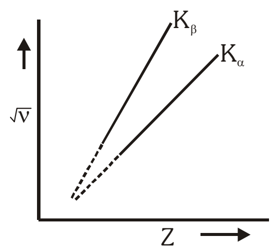
$$\sqrt{\nu} \propto (Z - b) \Rightarrow \nu \propto (Z - b)^2 \Rightarrow \nu = a\,(Z - b)^2 \quad ...(i)$$

Z = atomic number of target

ν = frequency of characteristic spectrum

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

a = proportionality constant



From Bohr Model $\quad \nu = RcZ^2\left[\dfrac{1}{n_1^2} - \dfrac{1}{n_2^2}\right]$ ...(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.	$\nu = RcZ^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$	**3.**	$\nu = Rc(Z-1)^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$
4.	$\frac{1}{\lambda} = RZ^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$	**4.**	$\frac{1}{\lambda} = R\,(Z-1)^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$

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

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

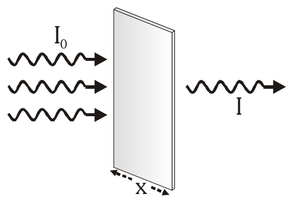
ABSORPTION OF X–RAY

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

I_0 = Intensity of incident X–ray

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

μ = absorption coefficient of material



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

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

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

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 .

Sol. $\mu = \dfrac{2.303}{x}\log\left(\dfrac{I_o}{I}\right) = \dfrac{2.303}{10}\log_{10}6 = \dfrac{2.303\times0.7781}{10} = 0.1752/\text{mm}$

DIFFRACTION OF X–RAY

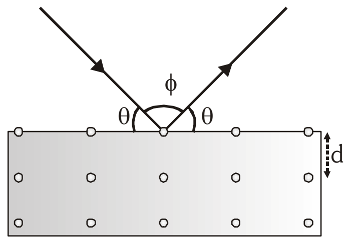
Diffraction of X–ray is possible by crystals because the interatomic spacing in a crystal lattice is order of wavelength of X–rays it was first verified by Lauve.

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

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

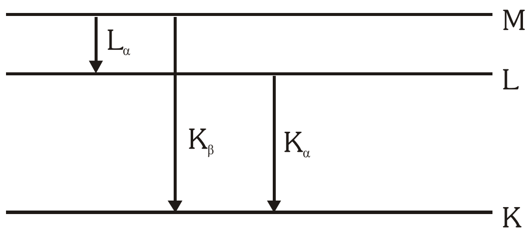
so if $\lambda > 2d$ diffraction is not possible i.e. solution of Bragg's equation is not possible.

PROPERTIES OF X–RAY

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

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

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



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

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

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

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

EXERCISE (S-1)

Photoelectric Effect :

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

MP0001

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

MP0002

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

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

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

MP0003

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

MP0004

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

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

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

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

MP0005

Wave Nature of Matter

6. Calculate the **NCERT**

(a) momentum, and

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

MP0006

7. The wavelength of light from the spectral emission line of sodium is 589 nm. Find the kinetic energy at which **NCERT**
(a) an electron, and
(b) a neutron, would have the same de-Broglie wavelength.

MP0007

8. (a) For what kinetic energy of a neutron will the associated de-Broglie wavelength be 1.40×10^{-10} m?
(b) Also find the de-Broglie wavelength of a neutron, in thermal equilibrium with matter, having an average kinetic energy of (3/2) k T at 300 K. **NCERT**

MP0008

9. The potential energy of a particle varies as $U(x) = E_0$ for $0 \le x \le 1$ and $U(x) = 0$ for $x > 1$
For $0 \le x \le 1$. de–Broglie wavelengths is λ_1 and for $x > 1$ the de–Broglie wavelength is λ_2.
Total energy of the particle is $2E_0$. Find $\frac{\lambda_1}{\lambda_2}$. **[JEE 2005]**

MP0009

Bohr's Theory

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

MP0010

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

MP0011

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

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

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

MP0014

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

MP0015

16. The total energy of an electron in the first excited state of the hydrogen atom is about –3.4 eV.

(a) What is the kinetic energy of the electron in this state? **NCERT**

(b) What is the potential energy of the electron in this state?

(c) Which of the answers above would change if the choice of the zero of potential energy is changed?

MP0016

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

MP0017

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

MP0018

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

MP0019

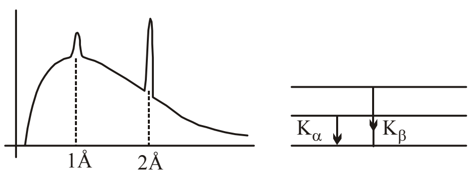
X-Rays

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

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

MP0021

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



MP0022

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

EXERCISE (S-2)

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

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

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

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

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

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

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

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

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

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

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

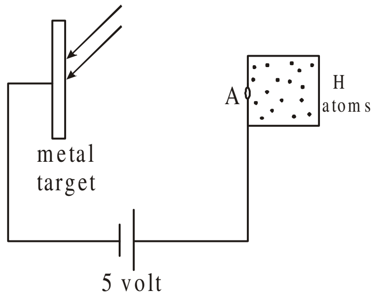
MP0030

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

9. A neutron of kinetic energy 65 eV collides inelastically with a singly ionized helium atom at rest. It is scattered at an angle of 90° with respect of its original direction.
(Given : Mass of he atom = 4×(mass of neutron), ionization energy of H atom =13.6 eV)
(i) Find the allowed values of the energy of the neutron & that of the atom after collision.
(ii) If the atom gets de-excited subsequently by emitting radiation, find the frequencies of the emitted radiation. **MP0032**

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

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



MP0034

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

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

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

MP0037

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

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

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

MP0040

18. In an X-ray tube the accelerating voltage is 20 KV. Two targets A and B are used one by one. For 'A' the wavelength of the K_α line is 62 pm. For 'B' the wavelength of the L_α line is 124 pm. The energy of the 'B' ion with vacancy in 'L' shell is 15.5 KeV higher than the atom of B.

[Take hc = 12400 eVÅ]

(i) Find λ_{min} in Å.

(ii) Can K_α – photon be emitted by 'A'? Explain with reason.

(iii) Can L – photons be emitted by 'B'? What is the minimum wavelength (in Å) of the characteristic X-ray that will be emitted by 'B'. **MP0041**

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

MP0042

EXERCISE (O-1)

SINGLE CORRECT TYPE QUESTIONS

Photoelectric Effect

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

and

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

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

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

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

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

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

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

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

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

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

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

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

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

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

MP0045

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

(A) equal to that of source A

(B) less than that of source A

(C) greater than that of source A

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

MP0046

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

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

MP0047

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

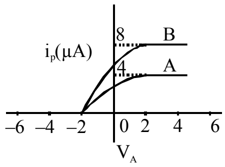
(A) 8 V (B) 6 V (C) 2 V (D) 4 **MP0048**

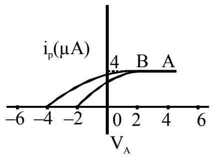
7. Light of frequency 7.21×10^{14} Hz is incident on a metal surface. Electrons with a maximum speed of 6.0×10^{5} m/s are ejected from the surface. The threshold frequency for photoemission of electrons is **NCERT**

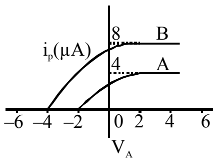
(A) 4.73×10^{14} Hz (B) 4.73×10^{10} Hz (C) 2.08×10^{10} Hz (D) None of these

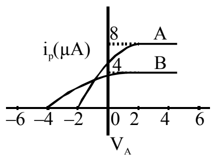
MP0049

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

(A) 

(B) 

(C) 

(D) 

MP0050

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

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

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

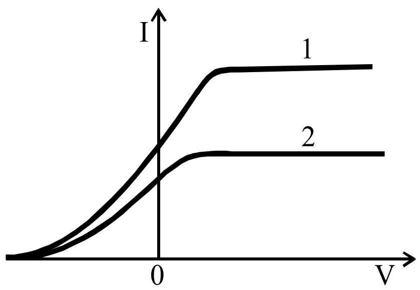
(B) Statement–1 is true, Statement–2 is true; Statement–2 is the correct explanation of Statement–1

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

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

MP0051

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



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

(C) Number of photoelectrons emmited per second

(D) None of these

MP0052

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

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

MP0053

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

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

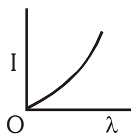
MP0054

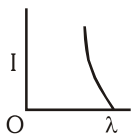
13. The time taken by a photoelectron to come out after the photon strikes is approximately- **[AIEEE - 2006]**

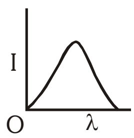
(A) 10^{-4} s (B) 10^{-10} s (C) 10^{-16} (D) 10^{-1} s

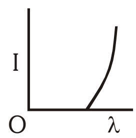
MP0055

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

(A) 

(B) 

(C) 

(D) 

MP0056

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

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

MP0057

Wave Nature oF Matter

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

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

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

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

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

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

MP0058

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

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

MP0059

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

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

MP0060

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

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

MP0061

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

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

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

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

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

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

MP0062

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

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

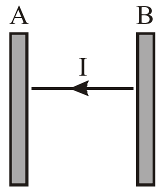
MP0063

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

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

MP0064

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



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

MP0065

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

because

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

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

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

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

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

MP0066

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

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

MP0067

Bohr's Theory

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

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

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

MP0068

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

and

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

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

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

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

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

MP0069

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

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

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

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

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

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

MP0070

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

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

MP0071

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

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

MP0072

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

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

MP0073

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

(A) – 4 (B) – 6 (C) – 8 (D) – 10

MP0074

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

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

MP0075

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

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

(B) 2 photons of energy 10.2 eV

(C) 2 photons of energy 3.4 eV

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

MP0076

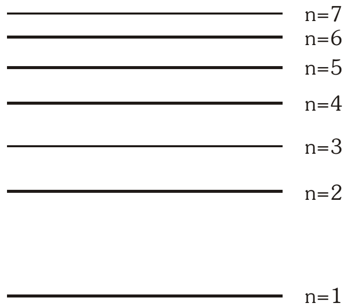
35. Two hydrogen atoms are in excited state with electrons residing in n = 2. First one is moving towards left and emits a photon of energy E_1 towards right. Second one is moving towards left with same speed and emits a photon of energy E_2 towards left. Taking recoil of nucleus into account during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

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

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

MP0077

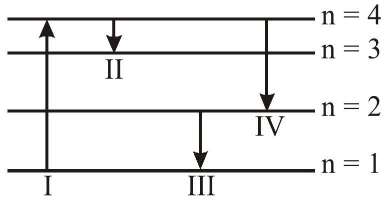
36. The maximum number of emission lines for atomic hydrogen that you would expect to see with naked eye if the only electronic levels involved are those shown in the figure, is



(A) 6 (B) 5 (C) 21 (D) ∞

MP0078

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



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

MP0079

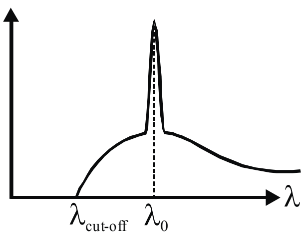
38. The largest wavelength in the ultraviolet region of the hydrogen spectrum is 122 nm. The smallest wavelength in the infrared region of the hydrogen spectrum (to the nearest integer) is **[JEE 2007]**

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

MP0080

X-Rays

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



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

Choose the correct statement from the following.

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

(B) Both A and R are correct but R is not the correct explanation of A.

(C) A is correct but R is wrong.

(D) Both A and R are wrong. **MP0081**

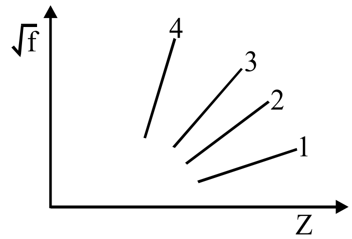
40. An X-ray tube is run at 50 kV. The current flowing in it is 20mA . The power of the tube is :
(A) 1000 W (B) 200 W (C) 20000 W (D) 20 W

MP0082

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

MP0083

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



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

MP0084

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

MP0085

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

MP0086

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

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

MP0087

46. What is the essential distinction between X–rays and γ–rays
(A) γ–rays have shorter wavelength than X–rays
(B) γ–rays are extraterrestrial, X–rays are man–made
(C) γ–rays have less penetrating power than X–rays
(D) γ–rays originate from within an atomic nucleus, X–rays from outside an atomic nucleus.

MP0088

47. Mosley law relates :
(A) Frequency of emitted X-ray with applied voltage
(B) Wavelength and intensity of X-ray.
(C) Frequency of emitted X-ray with atomic number
(D) Wavelength and angle of scattering.

MP0089

48. The intensity of gamma radiation from a given source is I. On passing through 36 mm of lead, it is reduced to I/8. The thickness of lead, which will reduce the intensity to I/2 will be- **[AIEEE-2005]**
(A) 6 mm (B) 9 mm (C) 18 mm (D) 12 mm

MP0090

49. The wavelength of K_α X-ray of an element having atomic number Z = 11 is λ . The wavelength of K_α X-ray of another element of atomic number Z' is 4λ. Then Z' is **[JEE' 2005 (Scr)]**
(A) 11 (B) 44 (C) 6 (D) 4

MP0091

50. Characteristic X-ray
(A) Have only discrete wavelength which are characteristic of the target.
(B) Have all the possible wavelength.
(C) Are characteristic of speed of projectile electrons.
(D) None

MP0092

51. Which of the following transitions in hydrogen atoms emit photons of highest frequency ? **[AIEEE - 2007]**
(A) n = 2 to n = 6 (B) n = 6 to n = 2 (C) n = 2 to n = 1 (D) n = 1 to n = 2

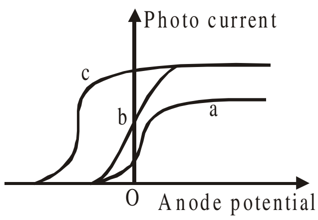
MP0093

MULTIPLE CORRECT TYPE QUESTIONS

52. Photoelectric effect supports quantum nature of light because
(A) there is minimum frequency of light below which no photoelectrons are emitted
(B) the maximum kinetic energy of photo-electrons depends only on the frequency of light and not on its intensity
(C) even when the metal surface is faintly illuminated, the photoelectrons leave the surface immediately
(D) electric charge of photo-electrons is quantized

MP0094

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



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

MP0095

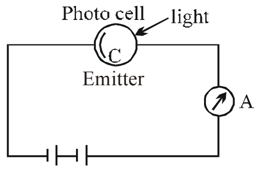
54. In photoelectric effect, stopping potential depends on
(A) frequency of the incident light
(B) intensity of the incident light by varies source distance
(C) emitter's properties
(D) frequency and intensity of the incident light

MP0096

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

MP0097

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



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

MP0098

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

MP0099

58. A small plate of area 1 cm^2 is placed at a distance of $\frac{1}{\sqrt{\pi}}$ m from an isotropic point source emitting light of frequency $\frac{1}{6.63}\times10^{14}$ Hz, at a power of 2.00 mW. Assume the plate to be normal to the incident photons. [where h = 6.63×10^{-34} J-s]. Select **CORRECT** alternative(s)
(A) Energy possessed by each photon is 10^{-20} J
(B) Photon emission rate is 2×10^{17} s^{-1}
(C) The fraction of area of beam intercepted by the plate is $\frac{1}{4}\times10^{-4}$
(D) The rate of photons striking the plate is 5×10^{12} per second.

MP0100

59. A metallic sphere of radius r remote from all other bodies is irradiated with a radiation of wavelength λ which is capable of causing photoelectric effect.
(A) the maximum potential gained by the sphere will be independent of its radius
(B) the net positive charge appearing on the sphere after a long time will depend on the radius of the sphere
(C) the maximum kinetic energy of the electrons emanating from the sphere will keep on declining with time
(D) the kinetic energy of the most energetic electrons emanating from the sphere initially will be independent of the radius of the sphere.

MP0101

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

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

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

MP0102

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

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

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

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

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

MP0103

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

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

(B) radius of orbit $\propto$ n

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

(D) angular momentum $\propto$ n

MP0104

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

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

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

MP0105

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

(A) Its atomic number is 3

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

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

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

MP0106

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

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

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

(C) B will contain some visible light.

(D) B will contain some infrared light.

MP0107

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

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

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

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

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

MP0108

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

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

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

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

(D) Perfectly inelastic collision can not take place.

MP0109

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

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

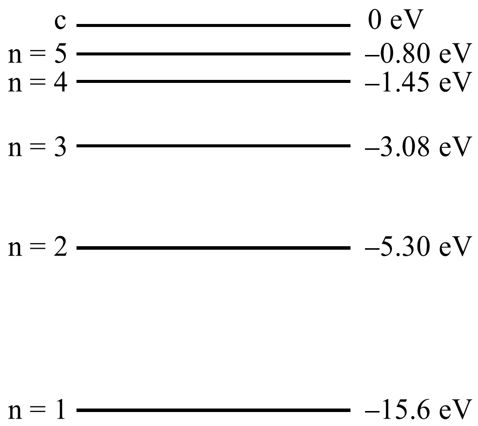
(B) minimum value of 'K' is 12.75 eV

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

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

MP0110

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



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

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

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

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

MP0111

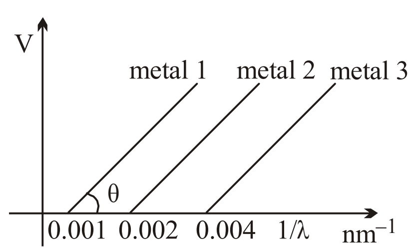
70. Suppose frequency of emitted photon is f_0 when electron of a stationary hydrogen atom jumps from a higher state m to a lower state n. If the atom is moving with a velocity v (<< c) and emits a photon of frequency f during the same transition, then which of the following statements are possible :-

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

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

MP0112

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



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

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

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

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

MP0113

MATRIX MATCH TYPE QUESTION

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

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

MP0114

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

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

MP0115

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

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

MP0116

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

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

Then choose the correct matching.

(A) (i) $\to$(RS) ; (ii) $\to$ (RS) ; (iii) $\to$(S) ; (iv) $\to$(PS)

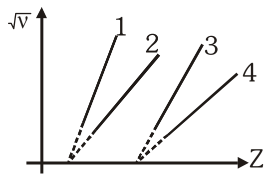
(B) (i) $\to$(RS) ; (ii) $\to$ (Q) ; (iii) $\to$(Q) ; (iv) $\to$(PS)

(C) (i) $\to$(RS) ; (ii) $\to$ (S) ; (iii) $\to$(S) ; (iv) $\to$(PRS)

(D) (i) $\to$(RS) ; (ii) $\to$ (Q) ; (iii) $\to$(Q) ; (iv) $\to$(PRS)

MP0117

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



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

MP0118

EXERCISE (O-2)

SINGLE CORRECT TYPE QUESTIONS

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

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

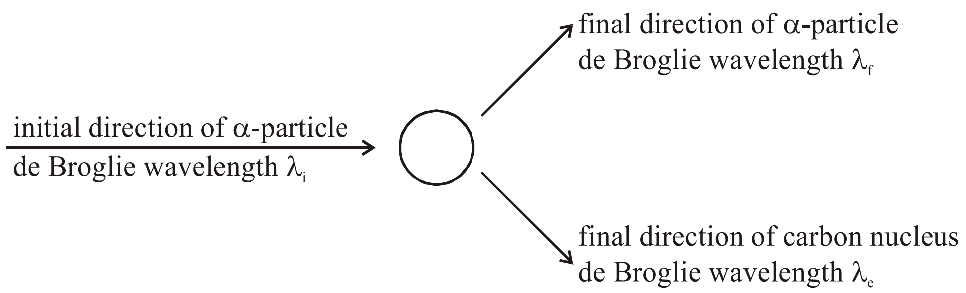
MP0119

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

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

MP0120

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



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

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

MP0121

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

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

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

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

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

MP0122

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

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

MP0123

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

[JEE' 2003 (Scr)]

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

MP0124

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

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

MP0125

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

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

MP0126

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

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

MP0127

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

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

MP0128

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

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

MP0129

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

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

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

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

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

MP0130

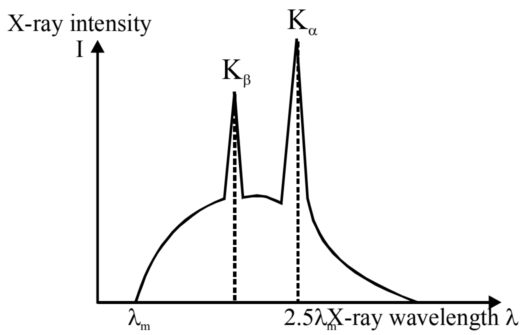
13. According to the Bohr theory of the hydrogen atom, electron starting in the 4th energy level and eventually ending in the ground state could produce a total of how many lines in the hydrogen spectra?

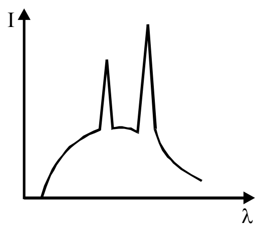
(A) 7 (B) 6 (C) 5 (D) 4

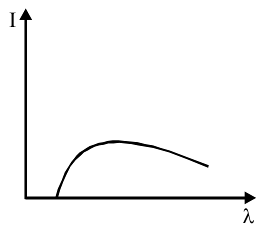
(E) 3

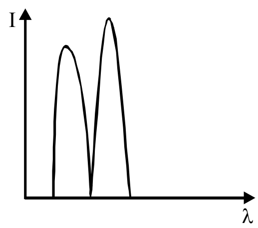
MP0131

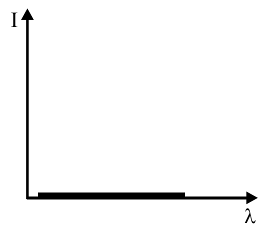
14. When an electron accelerated by potential difference U is bombarded on a specific metal the emitted X-ray spectrum obtained is shown in adjoining graph. If the potential difference is reduced to U/3, the correct spectrum is :-



(A)


(B)


(C)


(D)


MP0132

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

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

MP0133

MULTIPLE CORRECT TYPE QUESTIONS

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

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

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

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

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

MP0134

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

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

MP0135

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

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

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

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

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

MP0136

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

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

(B) $\lambda_1 > \lambda_2$

(C) threshold wavelength for A is greater than B

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

MP0137

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

(A) The fastest electron will reach the anode

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

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

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

MP0138

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

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

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

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

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

MP0139

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

(A) The gas is lithium

(B) The gas is helium

(C) The work function of photocathode is 8.5 eV

(D) The work function of photocathode is 5.5 eV

MP0140

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

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

MP0141

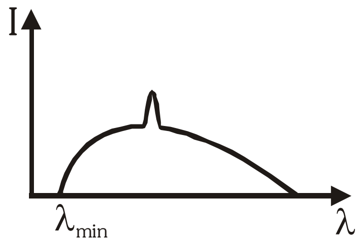
24. An X-ray tube has three main controls.

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

(ii) the filament current (I_f)

(iii) the accelerating voltage (V)

Figure shows a typical intensity distribution against wavelength.



Which of the following is **CORRECT**?

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

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

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

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

MP0142

COMPREHENSION TYPE QUESTIONS

Paragraph for Question 25 to 27

A mercury arc lamp provides 0.1 watt of ultra-violet radiation at a wavelength of $\lambda = 2537$ Å only. The photo tube (cathode of photo electric device) consists of potassium and has an effective area of 4 cm^2. The cathode is located at a distance of 1m from the radiation source. The work function for potassium is $\phi_0 = 2.22$ eV.

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

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

MP0143

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

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

MP0143

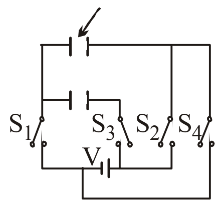
27. What is the cut off potential V_0 ?

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

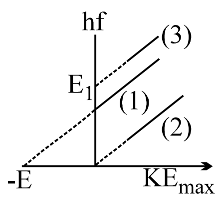
MP0143

Paragraph for question nos. 28 to 30

The circuit shown is placed in vacuum. Both the capacitors are identical and they have the same capacitance C. Light is incident on the left plate of the upper capacitor. When all the switches are open then the hf versus KE_{max} is shown by the straight line (1). In all the cases, we are measuring the KE_{max} when the electron reaches the opposite plate.



When only S_1 the switches and S_2 are closed, the graph becomes (2).
When only S_3 and S_4 are closed then the graph becomes (3).



28. What is the work function of the cathode?

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

MP0144

29. What is the value of eV?

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

MP0144

30. What is the value of E_1?

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

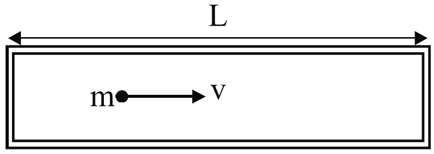
MP0144

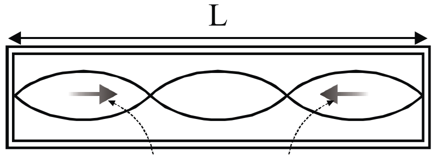
Paragraph for Question. 31 to 33

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

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

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





Matter waves travel in both directions.

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

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

MP0145

32. Confined particle's energy is given by

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

MP0145

33. Consider an oil drop from Millikan's oil drop experiment having diameter 1 μm confined between the plates separated by 10 μm. Density of oil is 900 kg/m³. What is minimum energy of such an oil drop? [Given : h = 6.63×10^{-34} Js]

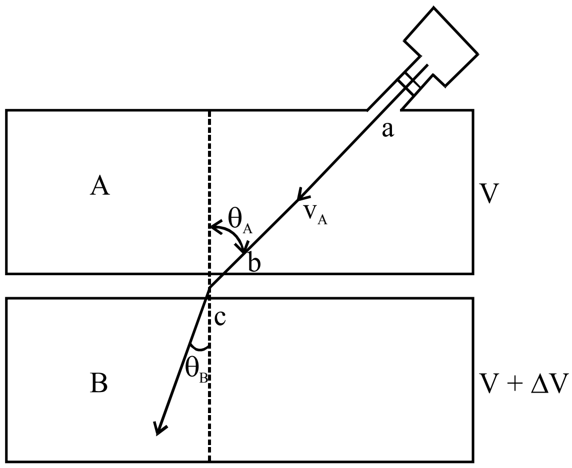
(A) 2.4×10^{-42} J (B) 1.2×10^{-42} J (C) 3.6×10^{-42} J (D) 4.8×10^{-42} J

MP0145

Paragraph for Question Nos. 34 to 36

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

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



The "refraction" of a pencil of electrons

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

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

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

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

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

MP0146

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

MP0146

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

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

MP0146

EXERCISE (JM)

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 10^{20} photons/second, the radiation belongs to apart of the spectrum called :- **[AIEEE - 2010]**

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

MP0151

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

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

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

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

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

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

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

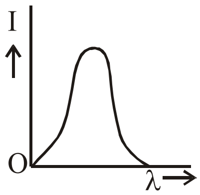
MP0153

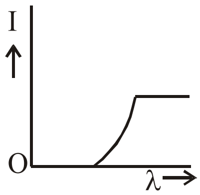
5. Hydrogen atom is excited from ground state to another state with principal quantum number equal to 4. Then the number of spectral lines in the emission spectra will be :- **[AIEEE-2012]**

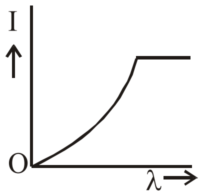
(1) 6 (2) 2 (3) 3 (4) 5

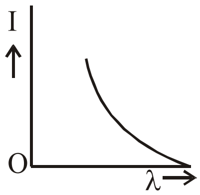
MP0154

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]**

(1) 

(2) 

(3) 

(4) 

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

MP0156

8. 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

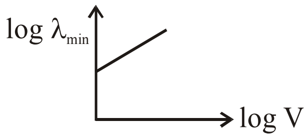
9. Radiation of wavelength λ, is incident on a photocell. The fastest emitted electron has speed v. If the wavelength of changed to $\frac{3\lambda}{4}$, the speed of the fastest emitted electron will be :-**[JEE Main-2016]**

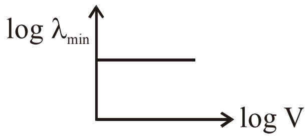
(1) $= v\left(\frac{3}{5}\right)^{1/2}$ (2) $> v\left(\frac{4}{3}\right)^{1/2}$ (3) $< v\left(\frac{4}{3}\right)^{1/2}$ (4) $= v\left(\frac{4}{3}\right)^{1/2}$

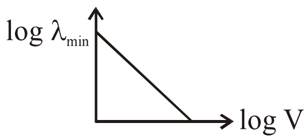
MP0159

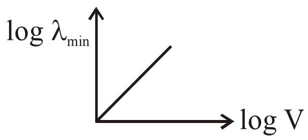
10. An electron beam is accelerated by a potential difference V to hit a metallic target to produce X-rays. It produces continuous as well as characteristic X-rays.If λ_{min} is the smallest possible wavelength of X-ray in the spectrum, the variation of log λ_{min} with log V is correctly represented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

[JEE Main-2017]

(1) 

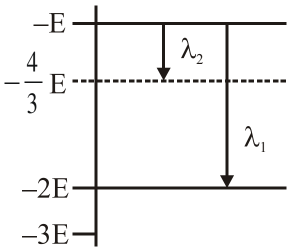
(2) 

(3) 

(4) 

MP0160

11. Some energy levels of a molecule are shown in the figure. The ratio of the wavelengths r = λ_1/λ_2, is given by : **[JEE Main-2017]**



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

MP0161

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

[JEE Main-2017]

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

MP0162

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

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

MP0163

SELECTED PROBLEMS FROM JEE-MAINS ONLINE PAPERS

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

(h_c = 12500 eV – Å) **[JEE Main-2019_Jan]**

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

MP0356

15. When a certain photosensistive surface is illuminated with monochromatic light of frequency ν, the stopping potential for the photo current is $-V_0/2$. When the surface is illuminated by monochromatic light of frequency ν/2, the stopping potential is $-V_0$. The threshold frequency for photoelectric emission is:

[JEE Main-2019_Jan]

(1) $\frac{3\nu}{2}$ (2) 2ν (3) $\frac{4}{3}\nu$ (4) $\frac{5\nu}{3}$

MP0357

16. An alpha-particle of mass m suffers 1-dimensional elastic coolision with a nucleus at rest of unknown mass. It is scattered directly backwards losing, 64% of its initial kinetic energy. The mass of the nucleus is :-

[JEE Main-2019_Jan]

(1) 4 m (2) 3.5 m (3) 2 m (4) 1.5 m

MP0358

17. 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-2019_Jan]**

(1) 2020 nm (2) 220 nm (3) 250 nm (4) 1700 nm

MP0359

18. 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-2019_April]

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

MP0360

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

(1) $\lambda = \frac{\lambda_1 + \lambda_2}{2}$ (2) $\frac{2}{\lambda} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$ (3) $\lambda = \sqrt{\lambda_1 \lambda_2}$ (4) $\frac{1}{\lambda^2} = \frac{1}{\lambda_1^2} + \frac{1}{\lambda_2^2}$

MP0361

20. 50 W/m^2 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 $1m^2$ surface area will be close to ($c = 3 \times 10^8$ m/s) :- **[JEE Main-2019_April]**

(1) 15×10^{-8} N (2) 35×10^{-8} N (3) 10×10^{-8} N (4) 20×10^{-8} N

MP0362

21. 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-2019_April]**

(1) 5.0×10^{-3} Ns (2) 3.5×10^{-6} Ns (3) 1.4×10^{-6} Ns (4) 6.3×10^{-4} Ns

MP0363

22. 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 : $h = 6.63 \times 10^{-34}$ Js ; $c = 3 \times 10^8$ ms^{-1}) **[JEE Main-2019_April]**

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

MP0364

23. 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-2019_April]**

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

MP0365

24. 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-2019_April]**

(1) 12.9 Å (2) 3.5 Å (3) 9.7 Å (4) 6.6 Å

MP0366

25. 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-2019_April]**

(1) n = 5 (2) n = 4 (3) n = 6 (4) n = 7

MP0367

26. A beam of electromagnetic radiation of intensity 6.4×10^{-5} W/cm^2 is comprised of wavelength, $\lambda = 310$ nm. It falls normally on a metal (work function $\varphi = 2$eV) of surface area of 1 cm^2. If one in 10^3 photons ejects an electron, total number of electrons ejected in 1 s is 10^x. (hc=1240 eVnm, 1eV=1.6×10^{-19} J), then x is____. **[JEE Main-2020_Jan]**

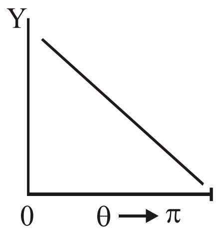
MP0368

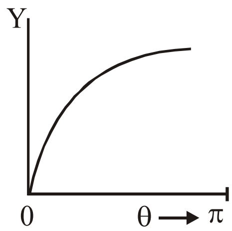
27. An electron (of mass m) and a photon have the same energy E in the range of a few eV. The ratio of the de-Broglie wavelength associated with the electron and the wavelength of the photon is (c = speed of light in vacuum) **[JEE Main-2020_Jan]**

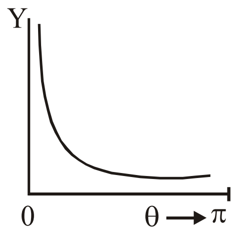
(1) $\left(\frac{E}{2m}\right)^{1/2}$ (2) $\frac{1}{c}\left(\frac{E}{2m}\right)^{1/2}$ (3) $c(2mE)^{1/2}$ (4) $\frac{1}{c}\left(\frac{2E}{m}\right)^{1/2}$

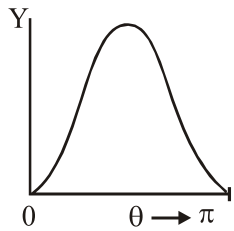
MP0369

28. The graph which depicts the results of Rutherform gold foil experiment with α-particales is :
θ : Scattering angle
Y : Number of scattered α-particles detected (Plots are schematic and not to scale) **[JEE Main-2020_Jan]**

(1) 

(2) 

(3) 

(4) 

MP0370

29. An electron (mass m) with initial velocity $\vec{v} = v_0\hat{i} + v_0\hat{j}$ is in an electric field $\vec{E} = -E_0\hat{k}$. If λ_0 is initial de-Broglie wavelength of electron, its de-Broglie wave length at time t is given by: **[JEE Main-2020_Jan]**

(1) $\frac{\lambda_0\sqrt{2}}{\sqrt{1+\frac{e^2E^2t^2}{m^2v_0^2}}}$ (2) $\frac{\lambda_0}{\sqrt{2+\frac{e^2E^2t^2}{m^2v_0^2}}}$ (3) $\frac{\lambda_0}{\sqrt{1+\frac{e^2E^2t^2}{2m^2v_0^2}}}$ (4) $\frac{\lambda_0}{\sqrt{1+\frac{e^2E_0^2t^2}{m^2v_0^2}}}$

MP0371

30. The energy required to ionise a hydrogen like ion in its ground state is 9 Rydbergs. What is the wavelength of the radiation emitted when the electron in this ion jumps from the second excited state to the ground state ? **[JEE Main-2020_Jan]**

(1) 35.8 nm (2) 24.2 nm (3) 8.6 nm (4) 11.4 nm

MP0372

31. In a hydrogen atom the electron makes a transition from (n + 1)th level to the nth level. If n>>l, the frequency of radiation emitted is proportional to : **[JEE Main-2020_Jan]**

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

MP0373

32. Particle A of mass $m_A = \frac{m}{2}$ moving along the x-axis with velocity v_0 collides elastically with another particle B at rest having mass $m_B = \frac{m}{3}$. If both particles move along the x-axis after the collision, the change $\Delta\lambda$ in de-Broglie wavelength of particle A, in terms of its de-Broglie wavelength (λ_0) before collision is : **[JEE Main-2020_Sep]**

(1) $\Delta\lambda = 4\lambda_0$ (2) $\Delta\lambda = \frac{5}{2}\lambda_0$ (3) $\Delta\lambda = 2\lambda_0$ (4) $\Delta\lambda = \frac{3}{2}\lambda_0$

MP0374

33. In the line spectra of hydrogen atom, difference between the largest and the shortest wavelengths of the Lyman series is 304 Å. The corresponding difference for the Paschan series in Å is : ______.

[JEE Main-2020_Sep]

MP0375

34. A particle of mass 200 MeV/c^2 collides with a hydrogen atom at rest. Soon after the collision the particle comes to rest, and the atom recoils and goes to its first excited state. The initial kinetic energy of the particle (in eV) is $\frac{N}{4}$. The value of N is : **[JEE Main-2020_Sep]**

(Given the mass of the hydrogen atom to be 1 GeV/c^2) ________.

MP0376

35. Assuming the nitrogen molecule is moving with r.m.s. velocity at 400 K, the de-Broglie wavelength of nitrogen molecule is close to :
(Given : nitrogen molecule weight : 4.64×10^{-26}kg, Boltzman constant : 1.38×10^{-23} J/K, Planck constant: 6.63×10^{-34} J.s) **[JEE Main-2020_Sep]**

(1) 0.34 Å (2) 0.24 Å (3) 0.20 Å (4) 0.44 Å

MP0377

EXERCISE (JA)

1. Which one of the following statements is **WRONG** in the context of X-rays generated from a X-ray tube ? **[JEE 2008]**
(A) Wavelength of characteristic X-rays decreases when the atomic number of the target increases
(B) Cut-off wavelength of the continuous X-rays depends on the atomic number of the target
(C) Intensity of the characteristic X-rays depends on the electrical power given to the X-rays tube
(D) Cut-off wavelength of the continuous X-rays depends on the energy of the electrons in the X-ray tube

MP0164

Paragraph for Question Nos. 2 to 4

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

2. The quantum number n of the state finally populated in He^+ ions is
(A) 2 (B) 3 (C) 4 (D) 5

MP0165

3. The wavelength of light emitted in the visible region by He^+ ions after collisions with H atoms is
(A) 6.5×10^{-7} m (B) 5.6×10^{-7} m (C) 4.8×10^{-7} m (D) 4.0×10^{-7} m

MP0165

4. The ratio of the kinetic energy of the n = 2 electron for the H atom to that of He^+ ion is
(A) $\frac{1}{4}$ (B) $\frac{1}{2}$ (C) 1 (D) 2

MP0165

Paragraph for Question Nos. 5 to 7

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

5. The allowed energy for the particle for a particular value of n is proportional to
(A) a^{-2} (B) $a^{-3/2}$ (C) a^{-1} (D) a^2

MP0166

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

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

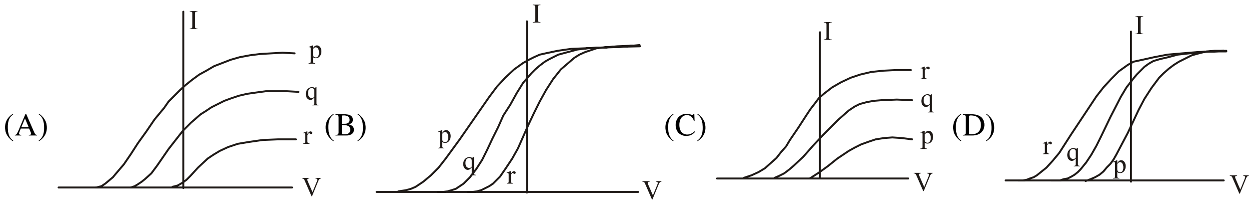
MP0166

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

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

MP0166

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



MP0167

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

[JEE 2010]

MP0168

Paragraph for Question Nos. 10 to 12

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

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

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

MP0169

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

(A) 2.76×10^{-46} kg m^2 (B) 1.87×10^{-46} kg m^2 (C) 4.67×10^{-47} kg m^2 (D) 1.17×10^{-47} kg m^2

MP0169

12. In a CO molecule, the distance between C (mass = 12 a.m.u.) and O (mass = 16 a.m.u.), where 1 a.m.u. = $\frac{5}{3} \times 10^{-27} kg$, is close to

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

MP0169

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

[JEE 2011]

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

MP0171

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

MP0172

15. A proton is fired from very far away towards a nucleus with charge Q = 120 e, where e is the electronic charge. It makes a closest approach of 10 fm to the nucleus. The de Broglie wavelength (in units of fm) of the proton at its start is (Take : The proton mass, $m_p = (5/3) \times 10^{-27}$ kg; $h/e = 4.2 \times 10^{-15}$ J.s/C; $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^{9}$ m/F; 1 fm = 10^{-15} m) **[JEE 2012]**

MP0173

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

MP0174

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

MP0175

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

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

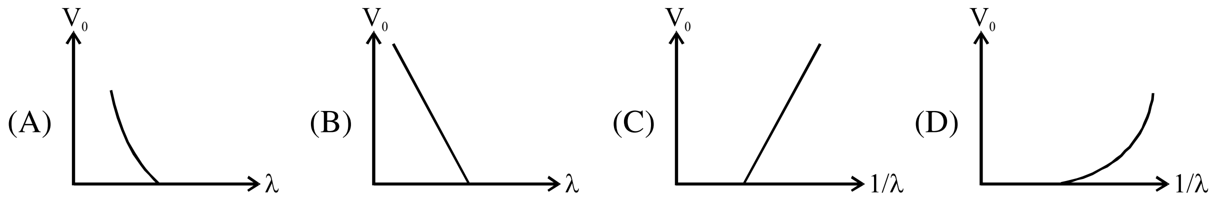
MP0176

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

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

MP0177

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



MP0178

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

[JEE Advanced-2015]

MP0179

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

λ(μm)	V_0 (Volt)
0.3	2.0
0.4	1.0
0.5	0.4

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

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

MP0180

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

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

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

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

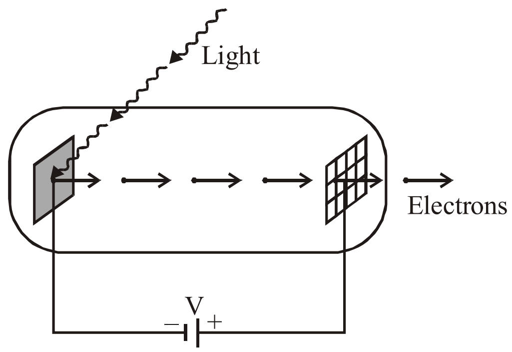
(D) Relative change in the angular momenta of two consecutive orbitals varies as 1/n

MP0181

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

MP0182

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



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

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

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

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

MP0183

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

MP0184

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

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

[JEE Advanced-2017]

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

MP0185

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

[JEE Advanced-2018]

MP0186

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

MP0187

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

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

[JEE Advanced-2019]

(1) $\lambda_e = 418$ nm

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

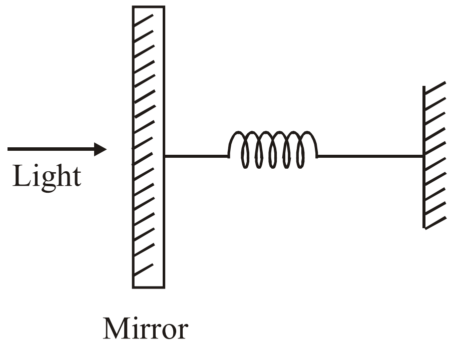
(3) m = 2

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

MP0188

31. A perfectly reflecting mirror of mass M mounted on a spring constitutes a spring-mass system of angular frequency Ω such that $\frac{4\pi M\Omega}{h} = 10^{24} m^{-2}$ with h as Planck's constant. N photons of wavelength $\lambda = 8\pi \times 10^{-6}$m strike the mirror simultaneously at normal incidence such that the mirror gets displaced by 1μm. If the value of N is $x \times 10^{12}$, then the value of x is________.
[Consider the spring as massless] **[JEE Advanced-2019]**

MP0189



32. In an X-ray tube, electrons emitted from a filament (cathode) carrying current I hit a target (anode) at a distance d from the cathode. The target is kept at a potential V higher than the cathode resulting in emission of continuous and characteristic X-rays. If the filament current I is decreased to $\frac{I}{2}$, the potential difference V is increased to 2V, and the separation distance d is reduced to $\frac{d}{2}$, then

[JEE Advanced-2020]

(A) the cut-off wavelength will reduce to half, and the wavelengths of the characteristic X-rays will remain the same

(B) the cut-off wavelength as well as the wavelengths of the characteristic X-rays will remain the same

(C) the cut-off wavelength will reduce to half, and the intensities of all the X-rays will decrease

(D) the cut-off wavelength will become two times larger, and the intensity of all the X-rays will decrease

MP0378

CBSE PREVIOUS YEAR'S QUESTIONS

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

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

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

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

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

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

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

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

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

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

(i) The number of atoms present initially.

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

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

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

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

(i) photoelectric current,

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

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

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

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

Given mass ${}_{3}^{6}Li$ = 6.015126 u; mass (neutron) = 1.0086654 u; mass (alpha particle) = 4.0026044 u and mass (triton) = 3.0100000u. Take 1u = 931 MeV/c^2. **[3; CBSE-2006]**

13. Ultraviolet radiations of different frequencies v_1 and v_2 are incident on two photosensitive materials having work functions W_1 and W_2 ($W_1 > W_2$) respectively. The kinetic energy of the emitted electrons is same in both the cases. Which one of the two radiations will be of higher frequency ? **[1; CBSE-2007]**

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

15. Draw a graph showing the variation of potential energy between a pair of nucleons as a function of their separation. Indicate the regions in which the nuclear force is (i) attractive, (ii) repulsive. **[2; CBSE-2007]**

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

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

Given:

mass of ${}_{20}^{40}Ca$ = 39.962589 u

mass of ${}_{20}^{40}Ca$ proton = 1.007825 u

mass of neutron – 1.008665 u and 1u = 931 MeV/C^2 **[3; CBSE-2007]**

18. An electron and alpha particle have the same de-Broglie wavelength associated with them How are their kinetic energies related to each other? **[1; CBSE-2008]**

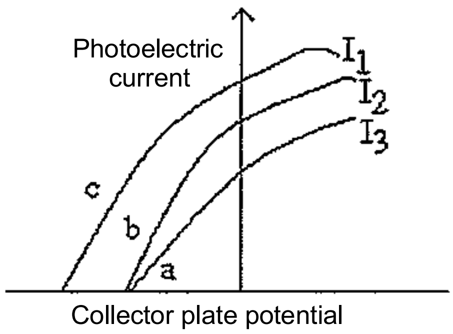
19. A nucleus ${}_{10}^{23}Ne$ undergoes decay and becomes ${}_{11}^{23}Na$. Calculate the maximum kinetic energy of electrons emitted assuming that the daughter nucleus and anti-neutrino carry negligible kinetic energy.

$$\left\{\begin{matrix} \text{Mass of } {}_{10}^{23}\text{Ne} = 22.994455\text{u} \\ \text{Mass of } {}_{11}^{23}\text{Na} = 22.989770\text{u} \\ 1\text{u} = 931.5\text{MeV}/\text{c}^2 \end{matrix}\right\}$$

[2; CBSE-2008]

20. An electromagnetic wave of wavelength λ is incident on a photosensitive surface of negligible work function. If the photo-electrons emitted from this surface have the de-Broglie wavelength λ_1 prove that $\lambda = \left(\frac{2mc}{h}\right)\lambda_1^2$ **[3; CBSE-2008]**

21. The figure shows a plot of three curves a, b, c showing the variation of photocurrent vs collector plate potential for three different intensities I_1, I_2 and I_3 having frequencies v_1, v_2 and v_3 respectively incident on a photosensitive surface. Point out the two curves of which the incident radiations have same frequency but different intensities. **[1; CBSE-2009]**



22. Two nuclei have mass numbers in the ratio 1 :3. What is the ratio of their nuclear densities? **[1; CBSE-2009]**

23. A radioactive nucleus 'A' Undergoes a series of decays according to the following scheme:

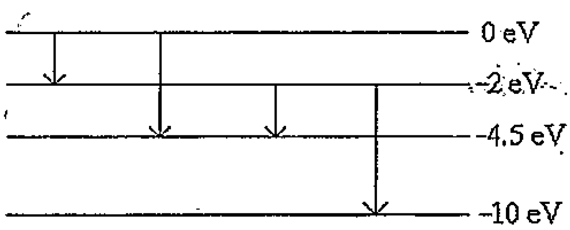
$$A \xrightarrow{\alpha} A_1 \xrightarrow{\beta} A_2 \xrightarrow{\alpha} A_3 \xrightarrow{\gamma} A_4$$

The mass number and atomic number of A4 are 172 and 69 respectively. What are these numbers for A? **[2; CBSE-2009]**

24. An electron and a proton are accelerated through the potential. Which one of the two has (i) greater . value of de-Broglie wavelength associated with it and (ii) less momentum? Justify your answer. **[3; CBSE-2009]**

25. (a) The energy levels of an atom are as shown below. Which of them will result in the transition of a photon of wavelength 275 nm?

(h) Which transition corresponds to emission of radiation of maximum wavelength? **[3; CBSE-2009]**



26. Define ionisation energy. What is its value for a hydrogen atom ? **[1; CBSE-2010]**

27. An α-particle and a proton are accelerated from rest by the same potential. Find the ratio of their de-Broglie wavelengths. **[2;CBSE-2010]**

28. Write Einstein's photoelectric equation. State clearly the three salient features observe in photoelectric effect, which can be explained on the basis of the above equation. **[2; CBSE-2010]**

29. Draw a plot of potential energy of a pair of nucleons as a function of their separation. Write two important conclusions which you can draw regarding the nature of nuclear forces. **[2; CBSE-2010]**

30. Draw a plot of the binding energy per nucleon as a function of mass number for a large number of nuclei, $2 \le A \le 240$. How do you explain the constancy of binding energy per nucleon in the range $30 < A < 170$ using the property that nuclear force is short-ranged ? **[2; CBSE-2010]**

31. (a) Write symbolically the β^- decay process of ${}^{32}_{15}P$.

(b) Derive an expression for the average life of a radionuclide. Give its relationship with the half-life. **[3; CBSE-2010]**

32. Write any two characteristic properties of nuclear force. **[1; CBSE-2011]**

33. Define the term 'stopping potential' in relation to photoelectric effect. **[1; CBSE-2011]**

34. Using the curve for the binding energy per nucleon as a function of mass number A, state clearly how the release in energy in the processes of nuclear fission and nuclear fusion can be explained. **[2; CBSE-2011]**

35. Draw a plot showing the variation of photoelectric current with collector plate potential for two different frequencies, $v_1 > v_2$, of incident radiation having the same intensity. In which case will the stopping potential be higher? Justify your answer. **[3; CBSE-2011]**

36. (a) Using de-Broglie's hypothesis, explain with the help of a suitable diagram, Bohr's second postulate of quantization of energy levels in a hydrogen atom,

(b) The ground state energy of hydrogen atom is –13.6eV. What are the kinetic and potential energies of the electron in this state? **[3; CBSE-2011]**

37. Define the terms (i) 'cut-off Voltage' and (ii) 'threshold frequency' in relation to the phenomenon of photoelectric effect

Using Eintein's photoelectric equation shows how the cut-off voltage and threshold frequency for a given photosensitive material can be determined with the help of a suitable plot/graph. **[3; CBSE-2012]**

38. Draw a plot of potential energy of a pair of nucleons as a function of their separations. Mark the regions where the nuclear is (i) attractive and (ii) repulsive. Write any two characteristic features of nuclear forces. **[3; CBSE-2012]**

39. In a Geiger-Marsden experiment, calculate the distance of closest approach to the nucleus of Z = 80, when a α-particle of 8Mev energy impinges on it before it comes momentarily to rest and reverses its direction.

How will the distance of closest approach be affected when the kinetic energy of the α-particle is doubles?

OR

The ground state energy of hydrogen atom is –13.6 eV. If an electron make a transition from the energy level –0.85 eV to –3.4 eV, calculate spectrum does his wavelength belong?**[3; CBSE-2012]**

40. Define the activity of a given radioactive substance. Write its S.I. unit. **[CBSE-2013]**

41. Write the expression for the deBroglie wavelength associated with a charged particle having charge 'q' and mass 'm', when it is accelerated by a potential V. **[CBSE-2013]**

42. Write Einstein's photoelectric equation and point out any two characteristic properties of photons on which this equation is based. Briefly explain the three observed features which can be explained' by this equation. **[CBSE-2013]**

43. Using Bohr's postulates, derive the expression for the frequency of radiation emitted when electron in hydrogen atom undergoes transition from higher energy state (quantum number n,) to the lower state, (n_f). When electron in hydrogen atom jumps from energy state $n_i = 4$ to $n_f = 3,2,1$, identify the spectral series to which the emission lines belong. **[CBSE-2013]**

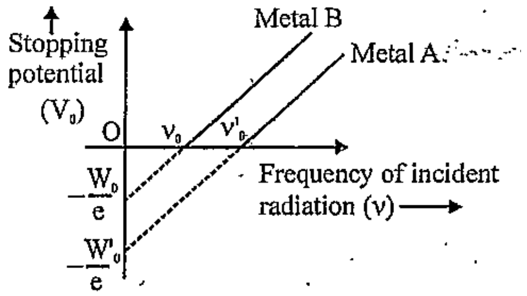
OR

(a) Draw the plot of binding energy per nucleon (BE/A) as a function of mass number A. Write two important conclusions that can be drawn regarding the nature of nuclear force.

(b) Use this graph to explain the release of energy in both the processes of nuclear fusion and fission,

(c) Write the basic nuclear process of neutron undergoing β-decay. Why is the detection of neutrinos found very difficult?

44. The graph shows the variation of stopping potential with frequency of incident radiation for two photosensitive metals A and B. Which one of the two has higher value of work-function? Justify your answer. **[CBSE-2014]**



45. Why is it found experimentally difficult to detect neutrinos in nuclear β-decay ? **[CBSE-2014]**

46. Using Rutherford model of the atom, derive the expression for the total energy of the electron in hydrogen atom. What is the significance of total negative energy possessed by the electron? **[CBSE-2014]**

OR

Using Bohr's postulates of the atomic model, derive the expression for radius of n^{th} electron orbit. Hence obtain the expression for Bohr's radius. **[CBSE-2014]**

47. When the electron orbiting in hydrogen atom in its ground state moves to the third excited state, show how the de Broglie wavelength associated with it would be affected. **[CBSE-2015]**

48. Define the terms 'stopping potential' and 'threshold frequency' in relation to photoelectric effect. How does one determine these physical quantities using einstein's equation ? **[CBSE-2015]**

49. A proton and an α particle are accelerated through the same potential difference. Which one of the two has (i) greater de-Broglie wavelength, and (ii) less kinetic energy ? Justify your answer. **[2 ; CBSE-2016]**

50. When is H_α line in the emission spectrum of hydrogen atom obtained ? Calculate the frequency of the photon emitted during this transition. **[2 ; CBSE-2016]**

OR

Calculate the wavelength of radiation emitted when electron in a hydrogen atom jumps from $n = \infty$ to $n = 1$. **[2 ; CBSE-2016]**

51. State two important properties of photon which are used to write Einstein's photoelectric equation. Define (i) stopping potential and (ii) threshold frequency, using Einstein's equation and drawing necessary plot between relevant quantities. **[3 ; CBSE-2016]**

52. (a) Derive the mathematical expression for law of radioactive decay for a sample of a radioactive nucleus. **[3 ; CBSE-2016]**

(b) How is the mean life of a given radioactive nucleus related to the decay constant ?

53. A 12·5 eV electron beam is used to excite a gaseous hydrogen atom at room temperature. Determine the wavelengths and the corresponding series of the lines emitted. **[CBSE-2017]**

54. Using photon picture of light, show how Einstein's photoelectric equation can be established. Write two features of photoelectric effect which cannot be explained by wave theory. **[CBSE-2017]**

55. Draw graphs showing variation of photoelectric current with applied voltage for two incident radiations of equal frequency and different intensities. Mark the graph for the radiation of higher intensity. **[CBSE-2018]**

56. Four nuclei of an element undergo fusion to form a heavier nucleus, with release of energy. Which of the two – the parent or the daughter necleus – would have higher binding energy per nucleon? **[CBSE-2018]**

57. If light of wavelength 412.5 nm is incident on each of the metals given below, which ones will show photoelectric emission and why? **[CBSE-2018]**

Metal	Work Function (eV)
Na	1.92
K	2.15
Ca	3.20
Mo	4.17

58. (a) State Bohr's psotulate to define stable orbits in hydrogen atom. How does de-Broglie's hypothesis explain the stability of these orbits?

(b) A hydrogen atom initially in the grond state absorbs a photon which excites it to the n = 4 level. Estimate the frequency of the photon. **[CBSE-2018]**

59. (a) Explain the processes of nuclear fission and nuclear fusion by using the plot of binding energy per nucleon (BE/A) versus the mass number A.

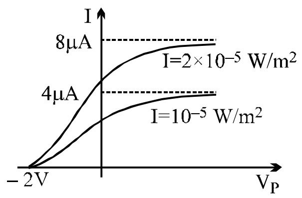
(b) A radioactive isotope has a half-lift of 10 years. How long will it take for the activity to resuce to 3.125%? **[CBSE-2018]**

ANSWER KEY

EXERCISE (S-1)

1. Ans. 6.59×10^{-34} Js   **2. Ans.** (a) 3.38×10^{-19} J = 2.11 eV (b) 3.0×10^{20} photons/s

3. Ans.



4. Ans. Use $eV_0 = h\nu - \phi_0$ for both sources. From the data on the first source, $\phi_0 = 1.40$ 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) 4.04×10^{-24} kg ms^{-1} (b) 0.164 nm

7. Ans. (a) 6.95×10^{-25} J = 4.34 μeV (b) 3.78×10^{-28} J = 0.236 neV

8. Ans. (a) 6.686×10^{-21} J = 4.174×10^{-2} eV (b) 0.145 nm

9. Ans. $\sqrt{2}$ **10. Ans.** 4   **11. Ans.** 0.55 eV   **12. Ans.** 7

13. Ans. 2   **14. Ans.** 820 nm.

15. Ans. Lyman series: 103 nm and 122 nm; Balmer series: 656 nm.

16. Ans. (a) +3.4 eV; (b) –6.8 eV; (c) potential energy

17. Ans. 2.56×10^{-13} m; –2.8 keV   **18. Ans.** 8   **19. Ans.** n = 24

20. Ans. 2

21. Ans. Use $\lambda = (hc/E)$ with $E = 5.1 \times 1.602 \times 10^{-10}$ J to get $\lambda = 2.43 \times 10^{-16}$ m.

22. Ans. 6210 eV   **23. Ans.** 400

EXERCISE (S-2)

1. Ans. 5   **2. Ans.** 1   **3. Ans.** 1.1×10^{12}

4. Ans. (a) 10^5 s^{-1}; (b) 286.18; (d) 111 s   **5. Ans.** $\lambda = \dfrac{2\lambda_1\lambda_2}{\sqrt{\lambda_1^2 + \lambda_2^2}}$

6. Ans. KE ≅ 151 eV, d_{least} = 0.5 Å   **7. Ans.** (i) 2 ; (ii) 13.6 eV ; (iii) 12.75 eV, 0.66 eV

8. Ans. 6.8 eV, 5×10^{15} Hz

9. Ans. (i) Allowed values of energy of neutron = 6.36 eV and 0.312 eV ; Allowed values of energy of He atom = 17.84 eV and 16.328 eV, (ii) 18.23×10^{14} Hz , 9.846×10^{15} Hz, 11.6×10^{15} Hz

10. Ans. 7.4 eV, 4.7 Volts   **11. Ans.** 6   **12. Ans.** 255   **13. Ans.** 3   **14. Ans.** 159

15. Ans. 255   **16. Ans.** 2   **17. Ans.** 98.25 eV

18. Ans. (i) 0.62Å, (ii) No, (iii) Yes 0.8 Å   **19. Ans.** 41

EXERCISE (O-1)

1. Ans. (A) 2. Ans. (A) 3. Ans. (B) 4. Ans. (B) 5. Ans. (B) 6. Ans. (C)
7. Ans. (A) 8. Ans. (A) 9. Ans. (D) 10. Ans. (B) 11. Ans. (B) 12. Ans. (A)
13. Ans. (B) 14. Ans. (B) 15. Ans. (D) 16. Ans. (D) 17. Ans. (D) 18. Ans. (A)
19. Ans. (D) 20. Ans. (A) 21. Ans. (C) 22. Ans. (D) 23. Ans. (D) 24. Ans. (B)
25. Ans. (A) 26. Ans. (A) 27. Ans. (A) 28. Ans. (A) 29. Ans. (A) 30. Ans. (A)
31. Ans. (A) 32. Ans. (D) 33. Ans. (B) 34. Ans. (A) 35. Ans. (B) 36. Ans. (B)
37. Ans. (D) 38. Ans. (B) 39. Ans. (A) 40. Ans. (A) 41. Ans. (D) 42. Ans. (B)
43. Ans. (C) 44. Ans. (D) 45. Ans. (D) 46. Ans. (D) 47. Ans. (C) 48. Ans. (D)
49. Ans. (C) 50. Ans. (A) 51. Ans. (C) 52. Ans. (A,B,C) 53. Ans. (A,B,D)
54. Ans. (A,C) 55. Ans. (A,B,C) 56. Ans. (B,C,D) 57. Ans. (A,D)
58. Ans. (A,B,C,D) 59. Ans. (A,B,D) 60. Ans. (A,B,C,D) 61. Ans. (B, D)
62. Ans. (A,C,D) 63. Ans. (A,B,C) 64. Ans. (A,C,D) 65. Ans. (A,C,D)
66. Ans. (B) 67. Ans. (A,C) 68. Ans. (A,C,D) 69. Ans. (A,B,C,D)
70. Ans. (A, B, C) 71. Ans. (A, C) 72. Ans. (A) P,R,S (B) P,Q (C) P,Q (D) R,S
73. Ans. (A)-QR, (B)-PS, (C)-QS, (D)-PR
74. Ans. (A) $\rightarrow$(P,R) ; (B) $\rightarrow$(Q,S) ; (C) $\rightarrow$(Q, S) ; (D)$\rightarrow$(P,R) 75. Ans. (B)
76. Ans. (A)$\rightarrow$ (S); (B) $\rightarrow$ (R); (C) $\rightarrow$ (Q); (D) $\rightarrow$ (P)

EXERCISE (O-2)

1. Ans. (D) 2. Ans. (C) 3. Ans. (A) 4. Ans. (B,D) 5. Ans. (B) 6. Ans. (A)
7. Ans. (B) 8. Ans. (D) 9. Ans. (C) 10. Ans. (C) 11. Ans. (D) 12. Ans. (B)
13. Ans. (B) 14. Ans. (B) 15. Ans. (D) 16. Ans. (A,C,D) 17. Ans. (D)
18. Ans. (A,B) 19. Ans. (B,C,D) 20. Ans. (B, C) 21. Ans. (A, B, D)
22. Ans. (B, C) 23. Ans. (B,C) 24. Ans. (A,C,D) 25. Ans. (A)
26. Ans. (A) 27. Ans. (B) 28. Ans. (A) 29. Ans. (A) 30. Ans. (B) 31. Ans. (B)
32. Ans. (C) 33. Ans. (B) 34. Ans. (C) 35. Ans. (D) 36. Ans. (A)

EXERCISE (JM)

1. Ans. (1) 2. Ans. (2) 3. Ans. (1) 4. Ans. (2) 5. Ans. (1)
6. Ans. (4) 7. Ans. (4) 8. Ans. (3) 9. Ans. (2) 10. Ans. (3)
11. Ans. (2) 12. Ans. (4) 13. Ans. (3)

SELECTED PROBLEMS FROM JEE-MAINS ONLINE PAPERS

14. Ans. (4) 15. Ans. (Bonus) or (1) 16. Ans. (1) 17. Ans. (3)
18. Ans. (4) 19. Ans. (4) 20. Ans. (4) 21. Ans. (1) 22. Ans. (3)
23. Ans. (1) 24. Ans. (3) 25. Ans. (1) 26. Ans. (11) 27. Ans. (2)
28. Ans. (3) 29. Ans. (3) 30. Ans. (4) 31. Ans. (2) 32. Ans. (1)
33. Ans. (10553) or (10553.14) 34. Ans. (51.00) 35. Ans. (2)

EXERCISE (JA)

1. Ans. (B)	**2. Ans. (C)**	**3. Ans. (C)**	**4. Ans. (A)**	**5. Ans. (A)**
6. Ans. (B)	**7. Ans. (D)**	**8. Ans. (A)**	**9. Ans. 3**	**10. Ans. (D)**
11. Ans. (B)	**12. Ans. (C)**	**13. Ans.** (A)	**14. Ans. 7**	**15. Ans. 7**
16. Ans. 1	**17. Ans. (A, C)**	**18. Ans. 2**	**19. Ans. (A), (C), (D)**	
20. Ans. (A,C)	**21. Ans. 2**	**22. Ans. (B)**	**23. Ans. (A, B, D)**	**24. Ans. 6**
25. Ans. (A)	**26. Ans. 5**	**27. Ans. (A)**	**28. Ans. 24 [23.60, 24.40]**	
29. Ans. 3 [3,3]	**30. Ans. (2,3)**	**31. Ans. (1.00)**	**32. Ans. (A,C)**	

ALLEN CAREER INSTITUTE KOTA (RAJASTHAN)

Chapter Contents 02

MODERN PHYSICS-2

Important Notes

MODERN PHYSICS-2

KEY CONCEPT

NUCLEAR PHYSICS

ATOMIC NUCLEUS

The atomic nucleus consists of two types of elementary particles, viz. protons and neutrons. These particles are called nucleons. The proton (denoted by p) has a charge +e and a mass $m_p = 1.6726 \times 10^{-27}$ kg, which is approximately 1840 times larger than the electron mass. The proton is the nucleus of the simplest atom with Z=1, viz the hydrogen atom.

The neutron (denoted by n) is an electrically neutral particle (its charge is zero). The neutron mass is 1.6749×10^{-27} kg. The fact that the mass of a neutron exceeds the mass of a proton by about 2.5 times the electronic masses is of essential importance. It follows from this that the neutron in free state (outside the nucleus) is unstable (radioactive). With half life equal to 12 min, the neutron spontaneously transforms into a proton by emitting an electron (e^-) and a particle called the antineutrino $(\bar{\nu})$.

This process can be schematically written as follows : ${}_0n^1 \rightarrow {}_1p^1 + {}_{-1}e^0 + \bar{\nu}$

The most important characteristics of the nucleus are the charge number Z (coinciding with atomic number of the element) and mass number A. The charge number Z is equal to the number of protons in the nucleus, and hence it determines the nuclear charge equal to Ze. The mass number A is equal to the number of nucleons in the nucleus (i.e., to the total number of protons and neutrons). Nuclei are symbolically designated as X_Z^A or ${}_ZX^A$ where X stands for the symbol of a chemical element.

For example, the nucleus of the oxygen atom is symbolically written as O_8^{16} or ${}_8O^{16}$.

The shape of nucleus is approximately spherical and its radius is approximately related to the mass number by

$R = 1.2\ A^{1/3} \times 10^{-15}\ m = 1.2 \times 10^{-15} \times A^{1/3}\ m$

Most of the chemical elements have several types of atoms differing in the number of neutrons in their nuclei. These varieties are called isotopes. For example carbon has three isotopes ${}_6C^{12}$, ${}_6C^{13}$, ${}_6C^{14}$. In addition to stable isotopes, there also exist unstable (radioactive) isotopes. Atomic masses are specified in terms of the atomic mass unit or unified mass unit (u). The mass of a neutral atom of the carbon ${}_6C^{12}$ is defined to be exactly 12 u.

$1u = 1.66056 \times 10^{-27}$ kg = 931.5 MeV.

BINDING ENERGY

The rest mass of the nucleus is smaller than the sum of the rest masses of nucleons constituting it. This is due to the fact that when nucleons combine to form a nucleus, some energy (binding energy) is liberated. The binding energy is equal to the work that must be done to split the nucleus into the particles constituting it.

The difference between the total mass of the nucleons and mass of the nucleus is called the mass defect of the nucleus represented by $\Delta m = [Zm_p + (A-Z)m_n] - m_{nuc}$

Multiplying the mass defect by the square of the velocity of light, we can find the binding energy of the nucleus.

$$BE = \Delta mc^2 = [(Zm_p + (A-Z)m_n) - m_{nuc}]c^2$$

If the masses are taken in atomic mass unit, the binding energy is given by

$$BE = [(Zm_p + (A-Z)m_n) - m_{nuc}]\ 931.5\ \text{MeV}$$

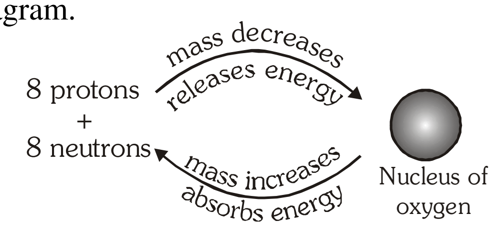
Let us take example of oxygen nucleus. It contains 8 protons and 8 neutrons.

We can discuss concept of binding energy by following diagram.

$8m_p + 8m_n >$ mass of nucleus of oxygen

For nucleus we apply mass energy conservation,

$$8m_p + 8m_n = \text{mass of nucleus} + \frac{\text{B.E.}}{c^2}$$



For general nucleus ${}_Z^AX$, mass defect = difference between total mass of nucleons and mass of the nucleus

$$\Delta m = [Zm_p + (A-Z)m_n] - M$$

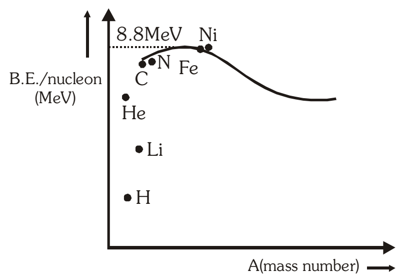
$$\text{B.E.} = \Delta mc^2 \text{ (joules)} = (\Delta m)_{\text{in amu}} \times 931.5 \text{ MeV}$$

Binding Energy per Nucleon

Stability of a nucleus does not depend upon binding energy of a nucleus but it depends upon binding energy per nucleon

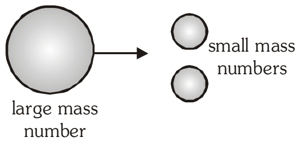
$$\text{B.E./nucleon} = \frac{\text{B.E.}}{\text{mass number}}$$

$$\text{Stability} \propto \frac{\text{B.E.}}{A}$$

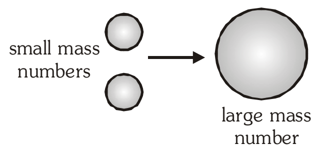


(i) B.E./A is maximum for A =62 (Ni), It is 8.79460 ± 0.00003 MeV/nucleon, means most stable nuclei are in the region of A = 62.

(ii) Heavy nuclei achieve stability by breaking into two smaller nuclei and this reaction is called fission reaction.



(iii) Nuclei achieve stability by combining and resulting into heavy nucleus and this reaction is called fusion reaction.



(iv) In both reactions products are more stable in comparison to reactants and Q value is positive.

NUCLEAR COLLISIONS

We can represent a nuclear collision or reaction by the following notation, which means X (a,b) Y

$$\underset{\text{(bombarding particle)}}{a} + \underset{\text{(at rest)}}{X} \rightarrow Y + b$$

We can apply :

(i) Conservation of momentum (ii) Conservation of charge (iii) Conservation of mass–energy

For any nuclear reaction $\underset{K_1}{a} + \underset{K_2}{X} \rightarrow \underset{K_3}{Y} + \underset{K_4}{b}$

By mass energy conservation

(i) $K_1 + K_2 + (m_\alpha + m_x)c^2 = K_3 + K_4 + (m_Y + m_b)c^2$

(ii) Energy released in any nuclear reaction or collision is called Q value of the reaction

(iii) $Q = (K_3 + K_4) - (K_1 + K_2) = \Sigma K_P - \Sigma K_R = (\Sigma m_R - \Sigma m_P)c^2$

(iv) If Q is positive, energy is released and products are more stable in comparison to reactants.

(v) If Q is negative, energy is absorbed and products are less stable in comparison to reactants.

$Q = \Sigma(\text{B.E.})_{\text{product}} - \Sigma(\text{B.E.})_{\text{reactants}}$

Ex. Let us find the Q value of fusion reaction

$^4He + {}^4He \rightarrow {}^8Be$, if $\frac{\text{B.E.}}{A}$ of He = X and $\frac{\text{B.E.}}{A}$ of Be = Y $\Rightarrow$ Q = 8Y – 8X

Q value for α decay $\quad {}_ZX^A \rightarrow {}_{Z-2}Y^{A-4} + {}_2He^4 \Rightarrow Q = K_\alpha + K_Y$ ....(i)

Momentum conservation, $p_Y = p_\alpha$ ...(ii)

$$K_\alpha = \frac{p^2}{2 \times m \times 4} \qquad K_Y = \frac{p^2}{2m(A-4)} = \frac{4K_\alpha}{A-4}$$

$$Q = K_\alpha + \frac{4K_\alpha}{A-4} = \frac{A}{A-4}K_\alpha \qquad K_\alpha = \frac{A-4}{A}Q$$

For α decay A > 210 which means maximum part of released energy is associated with K.E. of α. If Q is negative, the reaction is endoergic. The minimum amount of energy that a bombarding particle must have in order to initiate an endoergic reaction is called Threshold energy E_{th},

given by $E_{th} = -Q\left(\frac{m_1}{m_2} + 1\right)$ where m_1 = mass of the projectile.

E_{th} = minimum kinetic energy of the projectile to initiate the nuclear reaction

m_2 = mass of the target

Ex. How much energy must a bombarding proton possess to cause the reaction ${}_3Li^7 + {}_1H^1 \rightarrow {}_4Be^7 + {}_0n^1$ (Mass of ${}_3Li^7$ atom is 7.01600, mass of ${}_1H^1$ atom is 1.0783, mass of ${}_4Be^7$ atom is 7.01693)

Sol. Since the mass of an atom includes the masses of the atomic electrons, the appropriate number of electron masses must be subtracted from the given values.

Reactants : Total mass = $(7.01600 - 3\,m_e) + (1.0783 - 1\,m_e) = 8.0943 - 4m_e$

Products : Total mass = $(7.01693 - 4m_e) + 1.0087 = 8.02563 - 4m_e$

The energy is supplied as kinetic energy of the bombarding proton. The incident proton must have more than this energy because the system must possess some kinetic energy even after the reaction, so that momentum is conserved with momentum conservation taken into account, the minimum kinetic energy that the incident particle must possess can be found with the formula.

where, $Q = -[(8.02563 - 4m_e) - (8.0943 - 4\ m_e)]\ 931.5\ \text{MeV} = -63.96\ \text{MeV}$

$$E_{th} = -\left(1+\frac{m}{M}\right) Q = -\left(1+\frac{1}{7}\right)(-63.96) = 73.1\ \text{MeV}$$

NUCLEAR FISSION

In 1938 by Hahn and Strassmann. By attack of a particle splitting of a heavy nucleus (A > 230) into two or more lighter nuclei. In this process certain mass disappears which is obtained in the form of energy (enormous amount)

$$A + p \rightarrow \text{excited nucleus} \rightarrow B + C + Q$$

Hahn and Strassmann done the first fision of nucleus of U^{235}).

When U^{235} is bombarded by a neutron it splits into two fragments and 2 or 3 secondary neutrons and releases about 190 MeV ($\simeq$ 200 MeV) energy per fission (or from single nucleus)

Fragments are uncertain but each time energy released is almost same.

Possible reactions are

$$U^{235} + {}_0n^1 \rightarrow Ba + Kr + 3\,{}_0n^1 + 200\ \text{MeV or } U^{235} + {}_0n^1 \rightarrow Xe + Sr + 2\,{}_0n^1 + 200\ \text{MeV}$$

and many other reactions are possible.

- The average number of secondary neutrons is 2.5.
- Nuclear fission can be explained by using "liquid drop model" also.
- The mass defect Δm is about 0.1% of mass of fissioned nucleus
- About 93% of released energy (Q) is appear in the form of kinetic energies of products and about 7% part in the form of γ – rays.

NUCLEAR CHAIN REACTION :

The equation of fission of U^{235} is $U^{235} + {}_0n^1 \rightarrow Ba + Kr + 3\,{}_0n^1 + Q$.

These three secondary neutrons produced in the reaction may cause of fission of three more U^{235} and give 9 neutrons, which in turn, may cause of nine more fission of U^{235} and so on.

Thus a continuous 'Nuclear Chain reaction' would start.

If there is no control on chain reaction then in a short time ($\simeq 10^{-6}$ sec.) a huge amount of energy will be released. (This is the principle of 'Atom bomb'). If chain is controlled then produced energy can be used for peaceful purposes. For example nuclear reactor (Based on fission) are generating electricity.

NATURAL URANIUM :

It is mixture of U^{235} (0.7%) and U^{238} (99.3%).

U^{235} is easily fissionable, by slow neutron (or thermal neutrons) having K.E. of the order of 0.03 eV.

But U^{238} is fissionable with fast neutrons.

Note : Chain reaction in natural uranium can't occur

To improve the quality, percentage of U^{235} is increased to 3%.

The proposed uranium is called 'Enriched Uranium' (97% U^{238} and 3% U^{235})

LOSSES OF SECONDARY NEUTRONS :

Leakage of neutrons from the system : Due to their maximum K.E. some neutrons escape from the system.

Absorption of neutrons by U^{238} : Which is not fissionable by these secondary neutrons.

CRITICAL SIZE (OR MASS) :

In order to sustain chain reaction in a sample of enriched uranium, it is required that the number of lost neutrons should be much smaller than the number of neutrons produced in a fission process. For it the size of uranium block should be equal or greater than a certain size called **critical size**.

REPRODUCTION FACTOR :

$$(K) = \frac{\text{rate of production of neutrons}}{\text{rate of loss of neutrons}}$$

(i) If size of Uranium used is 'Critical' then K = 1 and the chain reaction will be steady or sustained (As in nuclear reaction)

(ii) If size of Uranium used is 'Super critical' then K > 1 and chain reaction will accelerate resulting in a explosion (As in atom bomb)

(iii) If size of Uranium used is 'Sub Critical' then K < 1 and chain reaction will retard and will stop.

NUCLEAR REACTOR (K = 1) : Credit $\rightarrow$ To Enricho Fermi

Construction :

- **Nuclear Fuel :** Commonly used are U^{235} , Pu^{239} .Pu^{239} is the **best**. Its critical size is less than critical size of U^{235}.
  But Pu^{239} is not naturally available and U^{235} is used in most of the reactors.
- **Moderator** : Its function is to slow down the fast secondary neutrons. Because only slow neutrons can bring the fission of U^{235}. The moderator should be light and it should not absorb the neutrons. Commonly, Heavy water (D_2O, molecular weight 20 gm.) Graphite etc. are used. These are rich of protons. Neutrons collide with the protons and interchange their energy. Thus neutrons get slow down.
- **Control rods** :They have the ability to capture the slow neutrons and can control the chain reaction at any stage. Boron and Cadmium are best absorber of neutrons.
- **Coolant** : A substance which absorb the produced heat and transfers it to water for further use. Generally coolant is water at high pressure

FAST BREADER REACTORS

The atomic reactor in which fresh fissionable fuel (Pu^{239}) is produced along with energy. The amount of produced fuel (Pu^{239}) is more than consumed fuel (U^{235})

- **Fuel :** Natural Uranium.
- **Process**: During fission of U^{235}, energy and secondary neutrons are produced. These secondary neutrons are absorbed by U^{238} and U^{239} is formed. This U^{239} converts into Pu^{239} after two beta decay. This Pu^{239} can be separated, its half life is 2400 years.

$${}_{92}U^{238} + {}_{0}n^{1} \longrightarrow {}_{92}U^{239} \xrightarrow{2\beta^-} {}_{94}Pu^{239} \text{ (best fuel of fission)}$$

This Pu^{239} can be used in nuclear weapons because of its small critical size than U^{235}.

- **Moderator :** Are not used in these reactors.
- **Coolant :** Liquid sodium

NUCLEAR FUSION :

It is the phenomenon of fusing two or more lighter nuclei to form a single heavy nucleus.

$$A + B \rightarrow C + Q \text{ (Energy)}$$

The product (C) is more stable then reactants (A and B) and $m_c < (m_a + m_b)$

and mass defect $\Delta m = [(m_a + m_b) - m_c]$ amu

Energy released is $E = \Delta m$ 931 MeV

The total binding energy and binding energy per nucleon C both are more than of A and B.

$\Delta E = E_c - (E_a + E_b)$

Fusion of four hydrogen nuclei into helium nucleus :

$4({}_1H^1) \rightarrow {}_2He^4 + 2\,{}_{+}\beta^0 + 2\,\nu + 26 \text{ MeV}$

- Energy released per fission >> Energy released per fusion
- Energy per nucleon in fission $\left[= \frac{200}{235} \simeq 0.85\text{MeV}\right]$ << energy per nucleon in fusion $\left[= \frac{24}{4} \simeq 6\text{MeV}\right]$

REQUIRED CONDITION FOR NUCLEAR FUSION

- **High temperature** :
  Which provide kinetic energy to nuclei to overcome the repulsive electrostatic force between them.
- **High Pressure (or density)** :
  Which ensure frequent collision and increases the probability of fusion. The required temperature and pressure at earth (lab) are not possible. These condition exist in the sun and in many other stars. The source of energy in the sun is nuclear fusion, where hydrogen is in plasma state and there protons fuse to form helium nuclei.

HYDROGEN BOMB

It is based on nuclear fusion and produces more energy than an atom bomb.

Pair production	Pair Annihilation
A γ–photon of energy more than 1.02 MeV,when interact with a nucleus produces pair of electron (e^-) and positron (e^+). The energy equivalent to rest mass of e^- (or e^+)=0.51 MeV. The energy equivalent to rest mass of pair $(e^- + e^+)$ = 1.02 MeV. For pair production Energy of photon $\geq$ 1.02 MeV. If energy of photon is more than 1.02 MeV, the extra energy (E–1.02) MeV devides approximately in equal amount to each particle as the kinetic energy or $(KE)_{e^- \text{ or } e^+} = \left[\frac{E_{Ph}-1.02}{2}\right]$MeV If E < 1.02 MeV, pair will not produce.	When electron and positron combines they annihilates to each other and only energy is released in the form of two gama photons.If the energy of electron and positron are negligible then energy of each γ–photon is 0.5/MeV

Ex. In a nuclear reactor, fission is produced in 1 g for U^{235} (235.0439) in 24 hours by slow neutrons (1.0087 u). Assume that ${}_{35}Kr^{92}$ (91.8973 u) and ${}_{56}Ba^{141}$ (140.9139 amu) are produced in all reactions and no energy is lost.

(i) Write the complete reaction (ii) Calculate the total energy produced in kilowatt hour.

Given 1u = 931 MeV.

Sol. The nuclear fission reaction is ${}_{92}U^{235} + {}_{0}n^{1} \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_{0}n^{1}$

Mass defect $\Delta m = [(m_u + m_n) - (m_{Ba} + m_{Kr} + 3m_n)] = 256.0526 - 235.8373 = 0.2153$ u

Energy released $Q = 0.2153 \times 931 = 200$ MeV. Number of atoms in 1 g $= \dfrac{6.02 \times 10^{23}}{235} = 2.56 \times 10^{21}$

Energy released in fission of 1 g of U^{235} is $E = 200 \times 2.56 \times 10^{21} = 5.12 \times 10^{23}$ MeV

$= 5.12 \times 10^{23} \times 1.6 \times 10^{-13} = 8.2 \times 10^{10}$ J

$= \dfrac{8.2 \times 10^{10}}{3.6 \times 10^{6}}$ kWh $= 2.28 \times 10^{4}$ kWh

Ex. It is proposed to use the nuclear fusion reaction : ${}_{1}H^{2} + {}_{1}H^{2} \rightarrow {}_{2}He^{4}$ in a nuclear reactor of 200 MW rating. If the energy from above reaction is used with at 25% efficiency in the reactor, how many grams of deuterium will be needed per day. (Mass of ${}_{1}H^{2}$ is 2.0141 u and mass of ${}_{2}He^{4}$ is 4.0026 u)

Sol. Energy released in the nuclear fusion is $Q = \Delta mc^2 = \Delta m(931)$ MeV (where Δm is in amu)

$Q = (2 \times 2.0141 - 4.0026) \times 931$ MeV $= 23.834$ MeV $= 23.834 \times 10^{6}$ eV

Since efficiency of reactor is 25%

So effective energy used $= \dfrac{25}{100} \times 23.834 \times 10^{6} \times 1.6 \times 10^{-19}$ J $= 9.534 \times 10^{-13}$ J

Since the two deuterium nuclei are involved in a fusion reaction,

therefore, energy released per deuterium is $\dfrac{9.534 \times 10^{-13}}{2}$.

For 200 MW power per day, number of deuterium nuclei required

$$= \frac{200 \times 10^{6} \times 86400}{\dfrac{9.534 \times 10^{-23}}{2}} = 3.624 \times 10^{25}$$

Since 2g of deuterium constitute 6×10^{23} nuclei, therefore amount of deuterium required is

$$= \frac{2 \times 3.624 \times 10^{25}}{6 \times 10^{23}} = 120.83 \text{ g/day}$$

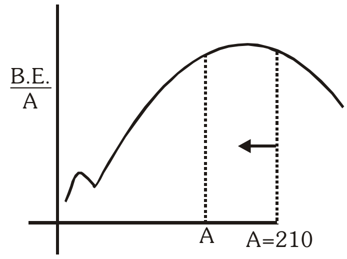
RADIOACTIVITY

The process of spontaneous disintegration shown by some unstable atomic nuclei is known as natural radioactivity. This property is associated with the emission of certain types of penetrating radiations, called radioactive rays, or Becquerel rays (α, β, γ–rays). The elements or compounds, whose atoms disintegrate and emit radiations are called radioactive elements. Radioactivity is a continuous, irreversible nuclear phenomenon.

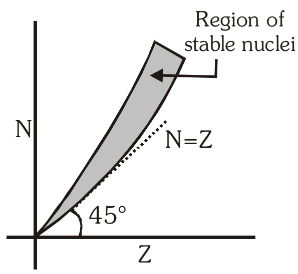
Radioactive Decays

Generally, there are three types of radioactive decays (i) α decay (ii) β^- and β^+ decay (iii) γ decay

- **α decay :** In α decay, the unstable nucleus emits an α particle. By emitting α particle, the nucleus decreases it's mass energy number and move towards stability. Nucleus having A>210 shows α decay.By releasing α particle, it can attain higher stability and Q value is positive.



- **β decay :** In beta decay (N/Z) ratio of nucleus is changed. This decay is shown by unstable nuclei. In beta decay, either a neutron is converted into proton or proton is converted into neutron. For better understanding we discuss N/Z graph. There are two type of unstable nuclides



  - **A type**

    For A type nuclides $(N/Z)_A > (N/Z)$ stable

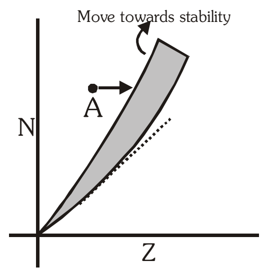
    To achieve stability, it increases Z by conversion of neutron into proton

    $_0n^1 \rightarrow {}_1p^1 + e^{-1} + \bar{\nu}$, $_ZX^A \rightarrow {}_{Z+1}Y^A + \underset{(\beta \text{ particle})}{e^{-1}} + \bar{\nu}$

    This decay is called β^{-1} decay.

    Kinetic energy available for e^{-1} and $\bar{\nu}$ is, $Q = K_\beta + K_{\bar{\nu}}$

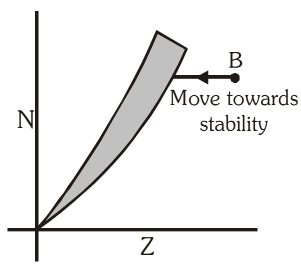
    K.E. of β satisfies the condition $0 < K_\beta < Q$



  - **B type**

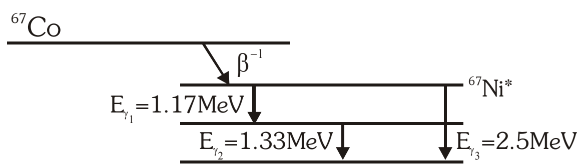
    For B type nuclides $(N/Z)_B < (N/Z)$ stable

    To achieve stability it decreases Z by the conversion of a proton into neutron. That is, $p \rightarrow n + \underset{(\text{positron})}{e^+} + \underset{(\text{neutrino})}{\nu}$, $_ZX^A \rightarrow {}_{Z-1}Y^A + \underset{(\beta^+ \text{particle})}{e^+} + \nu$



- **γ decay :** When an α or β decay takes place, the daughter nucleus is usually in higher energy state, such a nucleus comes to ground state by emitting a photon or photons.

  Order of energy of γ photon is 100 KeV



  e.g. $^{67}_{27}Co \rightarrow \underset{(\text{higher energy state})}{^{67}_{28}Ni^*} + \beta^- + \bar{\nu}$, $^{67}_{28}Ni^* \rightarrow {}^{67}_{28}Ni + \gamma$ photon

Properties of α, β and γ rays

Features	α–particles	β–particles	γ–rays
Identity	Helium nucleus or doubly ionised helium atom ($_2He^4$)	Fast moving electrons ($_{-}\beta^0$ or β^-)	Electromagnetic wave (photons)
Charge Mass	Twice of proton (+2e) $\approx 4m_p$ m_p–mass of proton	Electronic (– e) (rest mass of β) = (rest mass of electron)	Neutral rest mass = 0
Speed	1.4×10^7 m/s. to 2.2×10^7 m/s. (Only certain value between this range). Their speed depends on nature of the nucleus. So that it is a characteristic speed.	1% of c to 99% of c (All possible values between this range) β–particles come out with different speeds from the same type of nucleus. So that it can not be a characteristic speed.	Only $c = 3 \times 10^8$ m/s γ–photons come out with same speed from all types of nucleus. So, can not be a characteristic speed.
K.E.	≈ MeV	≈ MeV	≈ MeV
Energy spectrum	Line and discrete (or linear)	Continuous (or linear)	Line and discrete
Ionization power (α>β>γ)	10,000 times of γ–rays	100 times of γ–rays (or $\frac{1}{100}$ times of α)	1 (or $\frac{1}{100}$ times of β)
Penetration power (γ>β>α)	$\frac{1}{10000}$ times of γ–rays	$\frac{1}{100}$ times of γ–rays (100 times of α)	1(100 times of β)
Effect of electric or magnetic field	Deflection	Deflection (More than α)	No deflection
Explanation of emission	By Tunnel effect (or quantum mechanics)	By weak nuclear interactions	With the help of energy levels in nucleus

Laws of Radioactive Decay

1. The radioactive decay is a spontaneous process with the emission of α, β and γ rays. It is not influenced by external conditions such as temperature, pressure, electric and magnetic fields.
2. The rate of disintegration is directly proportional to the number of radioactive atoms present at that time i.e., rate of decay $\propto$ number of nuclei.

   Rate of decay = λ (number of nuclei) i.e. $\frac{dN}{dt} = -\lambda N$

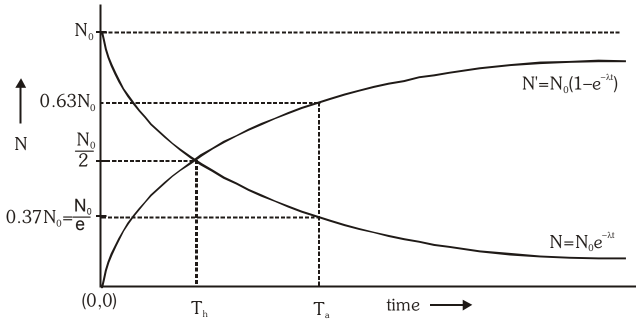
   where λ is called the decay constant. This equation may be expressed in the form $\frac{dN}{N} = -\lambda dt$.

$$\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int_0^t dt \Rightarrow \ell n\left(\frac{N}{N_0}\right) = -\lambda t$$

where N_0 is the number of parent nuclei at t=0. The number that survives at time t is therefore

$N=N_0e^{-\lambda t}$ and $t = \frac{2.303}{\lambda}\log_{10}\left(\frac{N_0}{N_t}\right)$ this function is plotted in figure.

Graph : Time versus N (or N')



- **Half life (T_h)** : It is the time during which number of active nuclei reduce to half of initial value.

If at t = 0 no. of active nuclei N_0 then at t = T_h number of active nuclei will be $\frac{N_0}{2}$

From decay equation $N = N_0e^{-\lambda t}$

$$\frac{N_0}{2} = N_0e^{-\lambda T_h} \Rightarrow T_h = \frac{\ell n(2)}{\lambda} = \frac{0.693}{\lambda} \approx \frac{0.7}{\lambda}$$

- **Mean or Average Life (T_a)** : It is the average of age of all active nuclei i.e.

$$T_a = \frac{\text{sum of times of existance of all nuclei in a sample}}{\text{initial number of active nuclei in that sample}} = \frac{1}{\lambda}$$

(i) At t = 0, number of active nuclei = N_0 then number of active nuclei at

$t = T_a$ is $N = N_0e^{-\lambda T_a} = N_0e^{-1} = \frac{N_0}{e} = 0.37N_0 = 37\%$ of N_0

(ii) Number nuclei which have been disintegrated within duration T_a is
$N' = N_0 - N = N_0 - 0.37\,N_0 = 0.63\,N_0 = 63\%$ of N_0

- $T_a = \frac{1}{\lambda} = \frac{T_h}{\ell n(2)} = \frac{T_h}{0.693} = 1.44\,T_h$
- Within duration $T_h \Rightarrow 50\%$ of N_0 decayed and 50% of N_0 remains active
- Within duration $T_a \Rightarrow 63\%$ of N_0 decayed and 37% of N_0 remains active

ACTIVITY OF A SAMPLE (A OR R) (OR DECAY RATE)

It is the rate of decay of a radioactive sample $R = -\frac{dN}{dt} = N\lambda$ or $R = R_0e^{-\lambda t}$

- Activity of a sample at any instant depends upon number of active nuclei at that instant.
  $R \propto N$ (or active mass) , $R \propto m$
- R also decreases exponentially w.r.t. time same as the number of active nuclei decreases.

- R is not a constant with N, m and time while λ, T_h and T_a are constant
- At $t = 0$, $R = R_0$ then at $t = T_h \Rightarrow R = \frac{R_0}{2}$ and at $t = T_a \Rightarrow R = \frac{R_0}{e}$ or $0.37\ R_0$
- Similarly active mass of radioactive sample decreases exponentially. $m = m_0 e^{-\lambda t}$
- Activity of m gm active sample (molecular weight M_w) is $R = \lambda N = \frac{0.693}{T_h}\left[\frac{N_{AV}}{M_W}\right]m$

here N_{AV} = Avogadro number = 6.023×10^{23}
SI UNIT of R : 1 becquerel (1 Bq)= 1 decay/sec
Other Unit is curie : 1 Ci = 3.70×10^{10} decays/sec
1 Rutherford : (1 Rd) $=10^6$ decays/s
Specific activity : Activity of 1 gm sample of radioactive substance. Its unit is Ci/gm
e.g. specific activity of radium (226) is 1 Ci/gm.

Ex. The half–life of cobalt–60 is 5.25 yrs. After how long does its activity reduce to about one eight of its original value?

Sol The activity is proportional to the number of undecayed atoms: In each half–life, the remaining sample decays to half of its initial value. Since $\left(\frac{1}{2}\right)\times\left(\frac{1}{2}\right)\times\left(\frac{1}{2}\right)=\frac{1}{8}$, therefore, three half–lives or 15.75 years are required for the sample to decay to 1/8th its original strength.

Ex. A count rate meter is used to measure the activity of a given sample. At one instant the meter shows 4750 counts per minute. Five minutes later it shows 2700 counts per minute.
(i) Find the decay constant. (ii) Also, find the half–life of the sample.

Sol. Initial activity $A_i = \left.\frac{-dN}{dt}\right|_{t=0} = \lambda N_0 = 4750$ ...(i) Final activity $A_f = \left.\frac{-dN}{dt}\right|_{t=5} = \lambda N = 2700$ ...(ii)

Dividing (i) by (ii), we get $\frac{4750}{2700} = \frac{N_0}{N_t}$

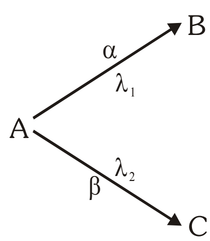
The decay constant is given by $\lambda = \frac{2.303}{t}\log\frac{N_0}{N_t} = \frac{2.303}{5}\log\frac{4750}{2700} = 0.113\ \text{min}^{-1}$

Half–life of the sample is $T = \frac{0.693}{\lambda} = \frac{0.693}{0.113} = 6.14$ min

- **Parallel radioactive disintegration**

Let initial number of nuclei of A is N_0 then at any time number of nuclei of

A, B & C are given by $N_0 = N_A + N_B + N_C \Rightarrow \frac{dN_A}{dt} = \frac{-d}{dt}(N_B + N_C)$



A disintegrates into B and C by emitting α, β particle.

Now, $\frac{dN_B}{dt} = -\lambda_1 N_A$ and $\frac{dN_C}{dt} = -\lambda_2 N_A \Rightarrow \frac{d}{dt}(N_B + N_C) = -(\lambda_1 + \lambda_2)N_A$

$\Rightarrow \frac{dN_A}{dt} = -(\lambda_1 + \lambda_2)N_A \Rightarrow \lambda_{eff} = \lambda_1 + \lambda_2 \Rightarrow t_{eff} = \frac{t_1 t_2}{t_1 + t_2}$

Ex. The mean lives of a radioactive substances are 1620 and 405 years for α–emission and β–emission respectively. Find out the time during which three fourth of a sample will decay if it is decaying both by α–emission and β–emission simultaneously.

Sol. When a substance decays by α and β emission simultaneously, the average rate of disintegration λ_{av} is given by

$\lambda_{av} = \lambda_\alpha + \lambda_\beta$ when λ_α = disintegration constant for α–emission only λ_β = disintegration constant for β–emission only

Mean life is given by $T_m = \frac{1}{\lambda}$, $\lambda_{av} = \lambda_\alpha + \lambda_\beta \Rightarrow \frac{1}{T_m} = \frac{1}{T_\alpha} + \frac{1}{T_\beta} = \frac{1}{1620} + \frac{1}{405} = \frac{1}{324}$

$\lambda_{av} \times t = 2.303 \log \frac{N_0}{N_t}$, $\frac{1}{324} t = 2.303 \log \frac{100}{25} \Rightarrow t = 2.303 \times 324 \log 4 = 449$ years.

Ex. A radioactive decay is given by $A \xrightarrow[t_{1/2}=8\text{ yrs}]{} B$

Only A is present at t=0. Find the time at which if we are able to pick one atom out of the sample, then probability of getting B is 15 times of getting A.

Sol.

		A	$\longrightarrow$	B
at	$t = 0$	N_0		0
at	$t = t$	N		$N_0 - N$

Probability of getting A, $P_A = \frac{N}{N_0}$

Probability of getting B, $P_B = \frac{N_0 - N}{N_0} \Rightarrow P_B = 15\, P_A \Rightarrow \frac{N_0 - N}{N_0} = 15 \frac{N}{N_0} \Rightarrow N_0 = 16N \Rightarrow N = \frac{N_0}{16}$

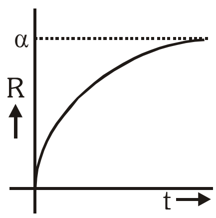
Remaining nuclei are $\frac{1}{16}$ th of initial nuclei, hence required time t = 4 half lives = 32 years

Radioactive Disintegration with Successive Production

$$\xrightarrow[(\alpha = \text{rate of production})]{\alpha} A \xrightarrow{\lambda} B$$

$\frac{dN_A}{dt} = \alpha = \lambda N_A$ ....(i)

when N_A in maximum $\frac{dN_A}{dt} = 0 = \alpha - \lambda N_A = 0$, N_A max = $\frac{\alpha}{\lambda} = \frac{\text{rate of production}}{\lambda}$



By equation (i) $\int_0^t \frac{dN_A}{\alpha - \lambda N_A} = \int_0^t dt$, Number of nuclei is $N_A = \frac{\alpha}{\lambda}\left(1 - e^{-\lambda t}\right)$

Ex. $\xrightarrow{10^{21}\text{ per sec}} A \xrightarrow{\lambda=\frac{1}{30}} B$

A shows radioactive disintegration and it is continuously produced at the rate of 10^{21} per sec. Find maximum number of nuclei of A.

Sol. At maximum, $r_{production} = r_{decay} \Rightarrow 10^{21} = \frac{1}{30}N \Rightarrow N = 30 \times 10^{21}$

Soddy and Fajan's Group Displacement Laws :

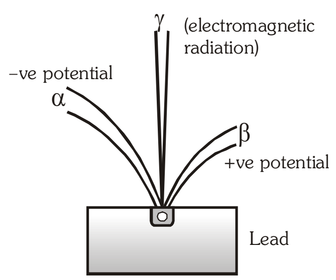
(i) **α–decay :** The emission of one α–particle reduces the mass number by 4 units and atomic number by 2 units. If parent and daughter nuclei are represented by symbols X and Y respectively then, ${}_{Z}X^{A} \rightarrow {}_{Z-2}Y^{A-4} + {}_{2}He^{4}(\alpha)$

(ii) **β–decay :** Beta particles are said to be fast moving electrons coming from the nucleus of a radioactive substance. Does it mean that a nucleus contains electrons? No, it is an established fact that nucleus does not contain any electrons. When a nucleus emits a beta particle, one of its neutrons breaks into a proton, an electron (i.e., β–particle) and an antineutrino $n \rightarrow p + e + \bar{\nu}$

where n= neutron p = proton e = β–particle

Thus emission of a beta particle is caused by the decay of a neutron into a proton. The daughter nucleus thus has an atomic number greater than one (due to one new proton in the nucleus) but same mass number as that of parent nucleus. Therefore, representing the parent and daughter nucleus by symbols X and Y respectively, we have ${}_{Z}X^{A} \rightarrow {}_{Z+1}Y^{A} + \beta + \bar{\nu}$

(iii) **γ–decay :** When parent atoms emit gamma rays, no charge is involved as these are neutral rays. Thus there is no effect on the atomic number and mass number of the parent nucleus. However the emission of γ–rays represents energy. Hence the emission of these rays changes the nucleus from an excited (high energy) state to a less excited (lower energy) state.



EXERCISE (S-1)

Nuclear Physics :

1. Suppose that the Sun consists entirely of hydrogen atom and releases the energy by the nuclear reaction, $4\,{}_1^1H \longrightarrow {}_2^4He$ with 26 MeV of energy released. If the total output power of the Sun is assumed to remain constant at 3.9×10^{26} W, find the time it will take to burn all the hydrogen. Take the mass of the Sun as 1.7×10^{30} kg.

MP0190

2. When two deuterons (${}_1H^2$) fuse to from a helium nucleus ${}_2He^4$, 23.6 MeV energy is released. Find the binding energy of helium if it is 1.1 MeV for each nucleon of deuterium.

MP0191

3. Highly energetic electrons are bombarded on a target of an element containing 30 neutrons. The ratio of radii of nucleus to that of helium nucleus is $(14)^{1/3}$. Find

(a) atomic number of the nucleus

(b) the frequency of K_α line of the X-ray produced. ($R = 1.1\times 10^7$ m^{-1} and $c = 3 \times 10^8$ m/s)

[JEE 2005]

MP0192

Radioactivity :

4. The kinetic energy of an $\alpha-$particle which flies out of the nucleus of a Ra^{226} atom in radioactive disintegration is 4.78 MeV. Find the total energy evolved during the escape of the $\alpha-$particle.

MP0193

5. U^{238} and U^{235} occur in nature in an atomic ratio 140 : 1. Assuming that at the time of earth's formation the two isotopes were present in equal amounts. Calculate the age of the earth.

(Half life of $u^{238} = 4.5 \times 10^9$ yrs & that of $U^{235} = 7.13 \times 10^8$ yrs)

MP0194

6. At t = 0, a sample is placed in a reactor. An unstable nuclide is produced at a constant rate R in the sample by neutron absorption. This nuclide β^- decays with half life τ. Find the time required to produce 80% of the equilibrium quantity of this unstable nuclide.

MP0195

EXERCISE (S-2)

1. An experiment is done to determine the half–life of radioactive substance that emits one β–particle for each decay process. Measurement show that 8.4 β are emitted each second by 2.5 mg of the substance. The atomic weight of the substance is 230. Find the half life of the substance.

MP0196

2. A wooden piece of great antiquity weighs 50 gm and shows C^{14} activity of 320 disintegrations per minute. Estimate the length of the time which has elapsed since this wood was part of living tree, assuming that living plants show a C^{14} activity of 12 disintegrations per minute per gm. The half life of C^{14} is 5730 yrs.

MP0197

3. A body of mass m_0 is placed on a smooth horizontal surface. The mass of the body is decreasing exponentially with disintegration constant λ. Assuming that the mass is ejected backward with a relative velocity u. Initially the body was at rest. Find the velocity of body after time t.

MP0198

4. A radionuclide with disintegration constant λ is produced in a reactor at a constant rate α nuclei per sec. During each decay energy E_0 is released. 20% of this energy is utilised in increasing the temperature of water. Find the increase in temperature of m mass of water in time t. Specific heat of water is S. Assume that there is no loss of energy through water surface.

MP0199

5. The element Curium ${}^{248}_{96}Cm$ has a mean life of 10^{13} seconds. Its primary decay modes are spontaneous fission and α decay, the former with a probability of 8% and the latter with a probability of 92%. Each fission releases 200 MeV of energy. The masses involved in α decay are as follows

${}^{248}_{96}Cm = 248.072220u$, ${}^{244}_{94}Pu = 244.064100u$ & ${}^{4}_{2}He = 4.002603\,u$.

Calculate the power output from a sample of 10^{20} Cm atoms. $(1\text{ u} = 931\text{ MeV}/c^2)$

MP0200

6. A small quantity of solution containing ^{24}Na radionuclide (half life 15 hours) of activity 1.0 microcurie is injected into the blood of a person. A sample of the blood of volume 1 cm^3 taken after 5 hours shows an activity of 296 distintegration per minute. Determine the total volume of blood in the body of the person. Assume that the radioactive solution mixes uniformly in the blood of the person.
(1 Curie = 3.7×10^{10} disintegrations per second)

MP0201

7. The positron is a fundamental particle with the same mass as that of the electron and with a charge equal to that of an electron but of opposite sign. When a positron and an electron collide, they may annihilate each other. The energy corresponding to their mass appears in two photons of equal energy. Find the wavelength of the radiation emitted. [Take : mass of electron $= (0.5/C^2)$MeV and $hC = 1.2 \times 10^{-12}$ MeV.m where h is the Plank's constant and C is the velocity of light in air]

MP0202

8. A π^+ meson of negligible initial velocity decays to a μ^+ (muon) and a neutrino. With what kinetic energy (in eV) does the muon move? (The rest mass of neutrino can be considered zero. The rest mass of the π^+ meson is 150 MeV and the rest mass of the muon is 100 MeV.) Take neutrino to behave like a photon. Take $\sqrt{2} = 1.41$.

MP0203

9. A radioactive decay counter is switched on at t = 0. A β - active sample is present near the counter. The counter registers the number of β-particles emitted by the sample. The counter registers 1×10^5 β-particles at t = 36 s and 1.11×10^5 β-particles at t = 108 s. Find $T_{1/2}$ of this sample

MP0204

10. A radioactive sample emits n β-particles in 2 sec. In next 2 sec it emits 0.75 n β-particles, what is the mean life of the sample? **[JEE 2003]**

MP0205

11. The age of a rock containing lead and uranium is equal to 1.5×10^9 yrs. The uranium is decaying into lead with half life equal to 4.5×10^9 yrs. Find the ratio of lead to uranium present in the rock, assuming initially no lead was present in the rock. (Given $2^{1/3} = 1.259$). **[JEE 2004]**

MP0206

EXERCISE (O-1)

SINGLE CORRECT TYPE QUESTIONS

Nuclear Physics :

1. In Rutherford's famous gold foil scattering experiment, he found that most alpha particles would pass through the foil undeflected. Which one of the following nuclear properties can be inferred from this observation?

(A) The nucleus must have a positive charge

(B) Most of the mass of an atom is in the nucleus

(C) The nucleus contains both protons neutrons

(D) The diameter of the nucleus is small compared to the diameter of the atom

(E) None of these

MP0207

2. Let u be denote one atomic mass unit. One atom of an element of mass number A has mass exactly equal to Au

(A) for any value of A (B) only for A = 1

(C) only for A = 12 (D) for any value of A provided the atom is stable

MP0208

3. If radius of the $^{27}_{13}\text{Al}$ nucleus is estimated to be 3.6 fermi, then the radius of $^{125}_{52}\text{Te}$ nucleus be nearly-

(A) 6 fermi (B) 8 fermi (C) 4 fermi (D) 5 fermi

[AIEEE - 2005]

MP0209

4. The surface area of a nucleus varies with mass number A as

(A) $A^{2/3}$ (B) $A^{1/3}$ (C) A (D) None

MP0210

5. A nucleus disintegrates into two nuclear parts which have their velocities in the ratio 2 : 1 The ratio of their nuclear sizes will be-

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

[AIEEE - 2004]

MP0211

6. The binding energy per nucleon for C^{12} is 7.68 MeV and that for C^{13} is 7.5 MeV. The energy required to remove a neutron from C^{13} is

(A) 5.34 MeV (B) 5.5 MeV (C) 9.5 MeV (D) 9.34 MeV

MP0212

7. The following nuclear reaction is an example of ${}_{6}^{12}C + {}_{2}^{4}H \rightarrow {}_{8}^{16}O$ + energy

(A) fission (B) fusion (C) alpha decay (D) beta decay

MP0213

8. Fast neutrons may most easily be slowed down by which one of the following methods?

(A) passing them through a substance rich in hydrogen

(B) allowing them to collide elastically with heavy nuclei

(C) using lead shielding

(D) passing them through an increasing potential gradient space

MP0214

9. A nuclear transformation is denoted by X(n, α) → ${}_{3}^{7}Li$. Which of the following is the nucleus of element X ?

(A) ${}_{6}^{12}C$ (B) ${}_{5}^{10}B$ (C) ${}_{5}^{9}B$ (D) ${}_{4}^{11}Be$

[AIEEE - 2005]

MP0215

10. A certain radioactive nuclide of mass number m_x disintegrates, with the emission of an electron and γ radiation only, to give second nuclide of mass number m_y. Which one of the following equation correctly relates m_x and m_y?

(A) $m_y = m_x + 1$ (B) $m_y = m_x - 2$ (C) $m_y = m_x - 1$ (D) $m_y = m_x$

MP0216

11. A nucleus with Z = 92 emits the following in a sequence : $\alpha, \alpha, \beta^-, \beta^-, \alpha, \alpha, \alpha, \alpha, \beta^-, \beta^-, \alpha, \beta^+, \beta^+, \alpha$. The Z of the resulting nucleus is-

(A) 76 (B) 78 (C) 82 (D) 74

[AIEEE - 2003]

MP0217

12. In an α-decay the Kinetic energy of α particle is 48 MeV and Q-value of the reaction is 50 MeV. The mass number of the mother nucleus is: (Assume that daughter nucleus is in ground state)

(A) 96 (B) 100 (C) 104 (D) none of these

MP0218

13. When U^{238} nucleus originally at rest, decays by emitting an alpha particle having a speed u, the recoil speed of the residual nucleus is-

(A) $\frac{4u}{238}$ (B) $-\frac{4u}{234}$ (C) $\frac{4u}{234}$ (D) $-\frac{4u}{238}$

[AIEEE - 2003]

MP0219

14. If a star converts all of its Helium into oxygen nucleus, find the amount of energy released per nucleus of oxygen. O = 15.9994 amu and He = 4.0026 amu

(A) 7.26 MeV (B) 7 MeV (C) 10.24 MeV (D) 5.12 MeV

[JEE' 2005 (Scr)]

MP0220

15. The nucleus of element X (A = 220) undergoes α-decay. If Q-value of the reaction is 5.5 MeV, then the kinetic energy of α-particle is :

(A) 5.4 MeV (B) 10.8 MeV (C) 2.7 MeV (D) None

[JEE 2003 (Scr)]

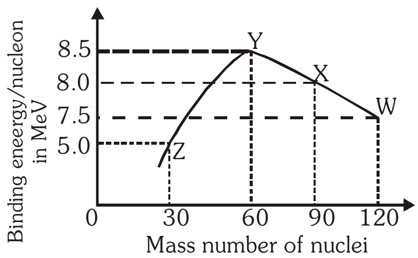
MP0221

16. In the uranium radioactive series the initial nucleus is $_{92}U^{238}$, and the final nucleus is $_{82}Pb^{206}$. When the uranium nucleus decays to lead, the number of α – particles emitted is.. and the number of β-particles emitted...

(A) 6, 8 (B) 8, 6 (C) 16, 6 (D) 32, 12

MP0222

17. Binding energy per nucleon versus mass number curve for nuclei is shown in figure. W, X, Y and Z are four nuclei indicated on the curve. The process that would release energy is :



(A) Y $\rightarrow$ 2Z (B) W $\rightarrow$ X + Z (C) W $\rightarrow$ 2Y (D) X $\rightarrow$ Y + Z

MP0223

18. An alpha nucleus of energy $\frac{1}{2}mv^2$ bombards a heavy nuclear target of charge Ze. Then the distance of closest approach for the alpha nucleus will be proportional to-

(A) v^2 (B) 1/m (C) $1/v^4$ (D) 1/Ze

[AIEEE - 2006]

MP0224

19. If the binding energy per nucleon in $^{7}_{3}Li$ and $^{4}_{2}He$ nuclei are 5.60 MeV and 7.06 MeV respectively, then in the reaction : $p + {}^{7}_{3}Li \rightarrow 2\,{}^{4}_{2}He$ energy of proton must be-

(A) 28.24 MeV (B) 17.28 MeV (C) 1.46 MeV (D) 39.2 MeV

[AIEEE - 2006]

MP0225

20. If M_0 is the mass of an oxygen isotope $_8O^{17}$, M_p and M_n are the masses of a proton and a neutron, respectively, the nuclear binding energy of the isotope is-

(A) $(M_o - 8M_p)c^2$ (B) $(M_o - 8Mp - 9M_n)c^2$

(C) M_oc^2 (D) $(M_o - 17M_n)c^2$

[AIEEE - 2007]

MP0226

21. In the options given below, let E denote the rest mass energy of a nucleus and n a neutron. The correct option is :-

(A) $E\left({}^{236}_{92}U\right) > E\left({}^{137}_{53}I\right) + E\left({}^{97}_{39}Y\right) + 2E(n)$ (B) $E\left({}^{236}_{92}U\right) < E\left({}^{137}_{53}I\right) + E\left({}^{97}_{39}Y\right) + 2E(n)$

(C) $E\left({}^{236}_{92}U\right) < E\left({}^{140}_{56}Ba\right) + E\left({}^{94}_{36}Kr\right) + 2E(n)$ (D) $E\left({}^{236}_{92}U\right) = E\left({}^{140}_{56}Ba\right) + E\left({}^{94}_{36}Kr\right) + 2E(n)$

[JEE 2007]

MP0227

Radoactivity :

22. The half–life of ^{131}I is 8 days. Given a sample of ^{131}I at time t = 0, we can assert that :

(A) no nucleus will decay before t = 4 days (B) no nucleus will decay before t = 8 days

(C) all nuclei will decay before t = 16 days (D) a given nucleus may decay at any time after t = 0

MP0228

23. Activity of a radioactive substance is R_1 at time t_1 and R_2 at time $t_2 (t_2 > t_1)$. Then the ratio $\frac{R_2}{R_1}$ is:

(A) $\frac{t_2}{t_1}$ (B) $e^{-\lambda(t_1+t_2)}$ (C) $e\left(\frac{t_1-t_2}{\lambda}\right)$ (D) $e^{\lambda(t_1-t_2)}$

MP0229

24. A particular nucleus in a large population of identical radioactive nuclei did survive 5 half lives of that isotope. Then the probability that this surviving nucleus will survive the next half life :

(A) $\frac{1}{32}$ (B) $\frac{1}{5}$ (C) $\frac{1}{2}$ (D) $\frac{1}{10}$

MP0230

25. A certain radio active substance has a half life of 5 years. Thus for a nucleus in a sample of the element, the probability of decay in ten years is

(A) 50% (B) 75% (C) 100% (D) 60%

MP0231

26. The activity of a sample reduces from A_0 to $A_0/\sqrt{3}$ in one hour. The activity after 3 hours more will be :-

(A) $\frac{A_0}{3\sqrt{3}}$ (B) $\frac{A_0}{9}$ (C) $\frac{A_0}{9\sqrt{3}}$ (D) $\frac{A_0}{27}$

MP0232

27. Half life of radium is 1620 years. How many radium nuclei decay in 5 hours in 5 gm radium? (Atomic weight of radium = 223)

(A) 9.1×10^{12} (B) 3.23×10^{15} (C) 1.72×10^{20} (D) 3.3×10^{17}

MP0233

28. The activity of a sample of radioactive material is A_1 at time t_1 and A_2 at time t_2 ($t_2 > t_1$). Its mean life is T.

(A) $A_1t_1 = A_2t_2$

(B) $\dfrac{A_1 - A_2}{t_2 - t_1}$ = constant

(C) $A_2 = A_1 e^{(t_1 - t_2)/T}$

(D) $A_2 = A_1 e^{(t_1/Tt_2)}$

MP0234

29. The decay constant of the end product of a radioactive series is

(A) zero
(B) infinite
(C) finite (non zero)
(D) depends on the end product.

MP0235

30. A radioactive substance is dissolved in a liquid and the solution is heated. The activity of the solution

(A) is smaller than that of element
(B) is greater than that of element
(C) is equal to that of element
(D) will be smaller or greater depending upon whether the solution is weak or concentrated.

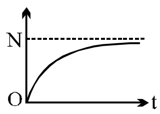
MP0236

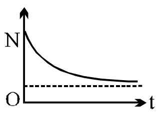
31. In a certain nuclear reactor, a radioactive nucleus is being produced at a constant rate = 1000 /s. The mean life of the radionuclide is 40 minutes. At steady state, the number of radionuclide will be

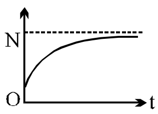
(A) 4×10^4
(B) 24×10^4
(C) 24×10^5
(D) 24×10^6

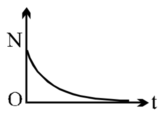
MP0237

32. In the above question, if there were 20×10^5 radionuclide at t = 0, then the graph of N v/s t is

(A) 

(B) 

(C) 

(D) 

MP0238

33. Which of the following cannot be emitted by radioactive substances during their decay ?

(A) Protons
(B) Neutrinos
(C) Helium nuclei
(D) Electrons

[AIEEE - 2003]
MP0239

34. A 280 days old radioactive substance shows an activity of 6000 dps, 140 days later it's activity becomes 3000dps. What was its initial activity.

(A) 20000 dps
(B) 24000 dps
(C) 12000 dps
(D) 6000 dps

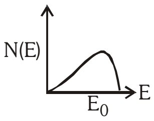
[JEE 2004 (Scr)]
MP0240

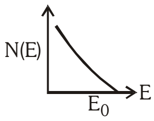
35. When $_3Li^7$ nuclei are bombarded by protons and the resultant nuclei are $_4Be^8$, the emitted particles will be-

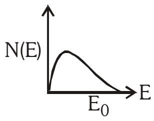
(A) alpha particles
(B) beta particles
(C) gamma photons
(D) neutrons

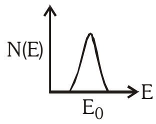
[AIEEE - 2006]
MP0241

36. The energy spectrum of β-particles [number N(E) as a function of β-energy E] emitted from a radioactive source is- **[AIEEE - 2006]**

(A) 

(B) 

(C) 

(D) 

MP0242

37. In gamma ray emission from a nucleus

(A) both the neutron number and the proton number change

(B) there is no change in the proton number and the neutron number

(C) only the neutron number changes

(D) only the proton number changes

[AIEEE-2007]
MP0243

38. The half-life period of a radioactive element X is same as the mean life time of another radioactive element Y. Initially they have the same number of atoms. Then-

(A) X will decay faster than Y

(B) Y will decay faster than X

(C) Y and X have same decay rate initially

(D) X and Y decay at same rate always

[AIEEE - 2007]
MP0244

39. Given a sample of Radium-226 having half-life of 4 days. Find the probability, a nucleus disintegrates within 2 half lives.

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

[JEE 2006]
MP0245

MATRIX MATCH TYPE QUESTION

40. Match the following Columns :-

	Column-I		**Column-II**
(A)	Nuclear fusion	(P)	Converts some matter into energy
(B)	Nuclear fission	(Q)	Generally occurs for nuclei with low atomic number
(C)	β–decay	(R)	Generally occurs for nuclei with higher atomic number
(D)	Exothermic nuclear reaction	(S)	Essentially proceeds by weak nuclear forces

[JEE 2006]
MP0246

41. Some laws/processes are given in **Column I**. Match these with the physical phenomena given in **Column II** and indicate your answer by darkening appropriate bubbles in the 4×4 matrix given in the ORS.

Column-I	Column-II
(A) Transition between two atomic energy levels	(P) Characteristic X-rays
(B) Electron emission from a material	(Q) Photoelectric effect
(C) Mosley's law	(R) Hydrogen spectrum
(D) Change of photon energy into kinetic energy of electrons	(S) β-decay

[JEE 2007]

MP0247

EXERCISE (O-2)

SINGLE CORRECT TYPE QUESTIONS

1. The binding energies of nuclei X and Y are E_1 and E_2 respectively. Two atoms of X fuse to give one atom of Y and an energy Q is released. Then:

(A) $Q = 2E_1 - E_2$ (B) $Q = E_2 - 2E_1$ (C) $Q = 2E_1 + E_2$ (D) $Q = 2E_2 + E_1$

MP0248

2. If each fission in a U^{235} nucleus releases 200 MeV, how many fissions must occurs per second to produce a power of 1 KW

(A) 1.325×10^{13} (B) 3.125×10^{13} (C) 1.235×10^{13} (D) 2.135×10^{13}

MP0249

3. The binding energies of the atom of elements A & B are E_a & E_b respectively. Three atoms of the element B fuse to give one atom of element A. This fusion process is accompanied by release of energy e. Then E_a, E_b are related to each other as

(A) $E_a + e = 3E_b$ (B) $E_a = 3E_b$ (C) $E_a - e = 3E_b$ (D) $E_a + 3E_b + e = 0$

MP0250

4. The rest mass of the deuteron, ${}_1^2H$, is equivalent to an energy of 1876 MeV, the rest mass of a proton is equivalent to 939 MeV and that of a neutron to 940 MeV. A deuteron may disintegrate to a proton and a neutron if it :

(A) emits a γ - ray photon of energy 2 MeV (B) captures a γ - ray photon of energy 2 MeV

(C) emits a γ - ray photon of energy 3 MeV (D) captures a γ - ray photon of energy 3 MeV

MP0251

5. The number of α and β^- emitted during the radioactive decay chain starting from ${}_{88}^{226}Ra$ and ending at ${}_{82}^{206}Pb$ is

(A) 3α & $6\beta^-$ (B) 4α & $5\beta^-$ (C) 5α & $4\beta^-$ (D) 6α & $6\beta^-$

MP0252

6. In a radioactive element the fraction of initial amount remaining after its mean life time is

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

MP0253

7. Two radioactive material A_1 and A_2 have decay constants of $10\lambda_0$ and λ_0. If initially they have same number of nuclei, the ratio of number of their undecayed nuclei will be (1/e) after a time

(A) $\frac{1}{\lambda_0}$ (B) $\frac{1}{9\lambda_0}$ (C) $\frac{1}{10\lambda_0}$ (D) 1

MP0254

8. 90% of a radioactive sample is left undecayed after time t has elapsed. What percentage of the initial sample will decay in a total time 2t :

(A) 20% (B) 19% (C) 40% (D) 38%

MP0255

9. A radioactive material of half-life T was produced in a nuclear reactor at different instants, the quantity produced second time was twice of that produced first time. If now their present activities are A_1 and A_2 respectively then their age difference equals:

(A) $\dfrac{T}{\ln 2}\left|\ln\dfrac{A_1}{A_2}\right|$ (B) $T\left|\ln\dfrac{A_1}{A_2}\right|$ (C) $\dfrac{T}{\ln 2}\left|\ln\dfrac{A_2}{2A_1}\right|$ (D) $T\left|\ln\dfrac{A_2}{2A_1}\right|$

MP0256

10. The half-life of substance X is 45 years, and it decomposes to substance Y. A sample from a meteorite was taken which contained 2% of X and 14% of Y by quantity of substance. If substance Y is not normally found on a meteorite, what is the approximate age of the meteorite?

(A) 270 years (B) 135 years (C) 90 years (D) 45 years

MP0257

11. At time t = 0, N_1 nuclei of decay constant λ_1 & N_2 nuclei of decay constant λ_2 are mixed . The decay rate of the mixture is :

(A) $N_1N_2e^{-(\lambda_1+\lambda_2)t}$ (B) $+\left(\dfrac{N_1}{N_2}\right)e^{-(\lambda_1-\lambda_2)t}$

(C) $+\left(N_1\lambda_1e^{-\lambda_1 t}+N_2\lambda_2e^{-\lambda_2 t}\right)$ (D) $+N_1\lambda_1 N_2\lambda_2 e^{-(\lambda_1+\lambda_2)t}$

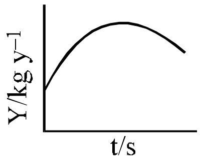
MP0258

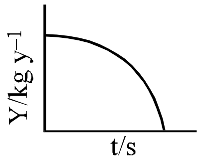
12. A radioactive nuclide can decay simultaneously by two different processes which have decay constants λ_1 and λ_2. The effective decay constant of the nuclide is λ, then :

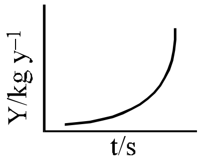
(A) $\lambda = \lambda_1 + \lambda_2$ (B) $\lambda = 1/2(\lambda_1 + \lambda_1)$ (C) $\dfrac{1}{\lambda}=\dfrac{1}{\lambda_1}+\dfrac{1}{\lambda_2}$ (D) $\lambda = \sqrt{\lambda_1\lambda_2}$

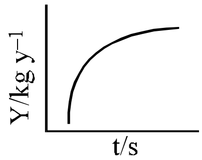
MP0259

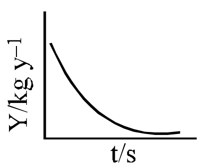
13. The radioactive nucleus of an element X decays to a stable nucleus of element Y. A graph of the rate of formation of Y against time would look like

(A) 

(B) 

(C) 

(D) 

(E) 

MP0260

14. The half life of a neutron is 800 sec. 10^8 neutrons at a certain instant are projected from one space station towards another space station, situated 3200 km away, with a velocity 2000 m/s. Their velocity remains constant during the journey. How many neutrons reach the other station?
(A) 50×10^6 (B) 25×10^6 (C) 80×10^5 (D) 25×10^5

MP0261

15. A radioactive source in the form of a metal sphere of diameter 3.2×10^{-3} m emits β-particle at a constant rate of 6.25×10^{10} particle/sec. The source is electrically insulated and all the β-particle are emitted from the surface. The potential of the sphere will rise to 1 V in time
(A) 180 μ sec (B) 90 μ sec (C) 18 μ sec (D) 9 μ sec

MP0262

16. In the nuclear fusion reaction,

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + n$$

given that the repulsive potential energy between the two nuclei is 7.7×10^{-14} J, the temperature at which the gases must be heated to initiate the reaction is nearly [Boltzmann's constant $k = 1.38 \times 10^{-23}$ J/K]-
(A) 10^7 K (B) 10^5 K (C) 10^3 K (D) 10^9 K

[AIEEE - 2003]
MP0263

17. The binding energy per nucleon of deuteron $(^{2}_{1}H)$ and helium nucleus $(^{4}_{2}He)$ is 1.1 MeV and 7 MeV respectively. If two deuteron nuclei react to form a single helium nucleus, then the energy released is-
(A) 13.9 MeV (B) 26.9 MeV (C) 23.6 MeV (D) 19.2 MeV

[AIEEE - 2004]
MP0264

MULTIPLE CORRECT TYPE QUESTIONS

18. When a nucleus with atomic number Z and mass number A undergoes a radioactive decay process:
(A) both Z and A will decrease, if the process is α decay
(B) Z will decrease but A will not change, if the process is β^+ decay
(C) Z will decrease but A will not change, if the process is β^- decay
(D) Z and A will remain unchanged, if the process is γ decay.

MP0265

19. When the atomic number A of the nucleus increases
(A) initially the neutron–proton ratio is constant = 1
(B) initially neutron–proton ratio increases and later decreases
(C) initially binding energy per nucleon increases and later decreases
(D) the binding energy per nucleon increases when the neutron–proton ratio increases.

MP0266

20. Let m_p be the mass of a proton, m_n the mass of a neutron, M_1 the mass of a $^{20}_{10}Ne$ nucleus and M_2 the mass of a $^{40}_{20}Ca$ nucleus. Then
(A) $M_2 = 2M_1$ (B) $M_2 > 2M_1$ (C) $M_2 < 2M_1$ (D) $M_1 < 10(m_n + m_p)$

MP0267

21. The decay constant of a radio active substance is 0.173 $(\text{years})^{-1}$. Therefore :

(A) Nearly 63% of the radioactive substance will decay in (1/0.173) year.

(B) half life of the radio active substance is (1/0.173) year.

(C) one -forth of the radioactive substance will be left after nearly 8 years.

(D) all the above statements are true.

MP0268

22. Which of the following statement(s) is/are correct?

(A) The rest mass of a stable nucleus is less than the sum of the rest masses of its separated nucleons.

(B) The rest mass of a stable nucleus is greater than the sum of the rest masses of its separated nucleons.

(C) In nuclear fusion, energy is released by fusion of two nuclei of medium mass (approx. 100 amu)

(D) In nuclear fission, energy is released by fragmentation of a very heavy nucleus.

MP0269

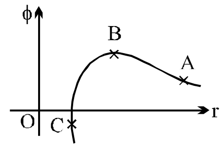
23. The graph shown by the side shows the variation of potential energy ϕ of a proton with its distance 'r' from a fixed sodium nucleus, as it approaches the nucleus, placed at origin O. Then the portion.

(A) AB indicates nuclear repulsion

(B) AB indicates electrostatic repulsion

(C) BC indicates nuclear attraction

(D) BC represents electrostatic interaction



MP0270

24. The instability of the nucleus can be due to various causes. An unstable nucleus emits radiations if possible to transform into less unstable state. Then the cause and the result can be

(A) a nucleus of excess nucleons is α active

(B) an excited nucleus of excess protons is β^- active

(C) an excited nucleus of excess protons is β^+ active

(D) an nucleus of excess neutrons is β^- active

MP0271

25. In β-decay, the Q-value of the process is E. Then

(A) K.E. of a β-particle cannot exceed E.

(B) K.E. of anti neutrino emitted lies between Zero and E.

(C) N/Z ratio of the nucleus is altered.

(D) Mass number (A) of the nucleus is altered.

MP0272

26. Consider the following nuclear reactions and select the correct statements from the options that follow.

Reaction I : $n \rightarrow p + e^- + \overline{v}$ **Reaction II :** $p \rightarrow n + e^+ + v$

(A) Free neutron is unstable, therefore reaction I is possible

(B) Free proton is stable, therefore reaction II is not possible

(C) Inside a nucleus, both decays (reaction I and II) are possible

(D) Inside a nucleus, reaction I is not possible but reaction II is possible.

MP0273

27. When the nucleus of an electrically neutral atom undergoes a radioactive decay process, it will remain neutral after the decay if the process is :

(A) α decay (B) β^- decay (C) γ decay (D) K-capture

MP0274

MATRIX MATCH TYPE QUESTION

28. In the following, column I lists some physical quantities & the column II gives approx. energy values associated with some of them. Choose the appropriate value of energy from column II for each of the physical quantities in column I and write the corresponding letter A, B, C etc. against the number (i), (ii), (iii), etc. of the physical quantity in the answer book. In your answer, the sequence of column I should be maintained.

	Column I		**Column II**
(i)	Energy of thermal neutrons	(A)	0.025 eV
(ii)	Energy of X-rays	(B)	0.5 eV
(iii)	Binding energy per nucleon	(C)	3 eV
(iv)	Photoelectric threshold of metal	(D)	20 eV
		(E)	10 keV
		(F)	8 MeV

MP0275

EXERCISE - JM

1. This question contains Statement-1 and Statement-2. Out of the four choices given after the statements, choose the one that best describes the two statements.

Statement-1 : Energy is released when heavy nuclei undergo fission or light nuclei undergo fusion.

Statement-2 : For heavy nuclei, binding energy per nucleon increases with increasing Z while for light nuclei it decreases with increasing Z.

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

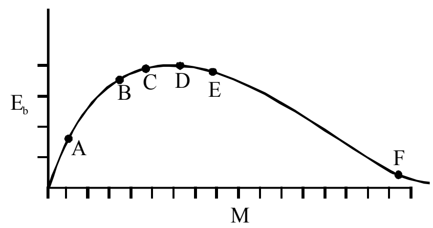
(2) Statement-1 is true, Statement-2 is true; Statement-2 is a correct explanation for Statement-1.

(3) Statement-1 is true, Statement-2 is true; Statement-2 is not a correct explanation for Statement-1.

(4) Statement-1 is true, Statement-2 is false.

[AIEEE - 2008]
MP0276

2.



The above is a plot of binding energy per nucleon E_b, against the nuclear mass M; A, B, C, D, E, F correspond to different nuclei. Consider four reactions :

(i) $A + B \rightarrow C + \varepsilon$ (ii) $C \rightarrow A + B + \varepsilon$

(iii) $D + E \rightarrow F + \varepsilon$ (iv) $F \rightarrow D + E + \varepsilon$

where ε is the energy released ? In which reactions is ε positive ?

(i) $A + B \rightarrow C + \varepsilon$ (ii) $C \rightarrow A + B + \varepsilon$ (iii) $D + E \rightarrow F + \varepsilon$ (iv) $F \rightarrow D + E + \varepsilon$

(1) (ii) and (iv) (2) (ii) and (iii) (3) (i) and (iv) (4) (i) and (iii)

[AIEEE - 2009]
MP0277

Directions : Questions number 3 – 4 are based on the following paragraph.

A nucleus of mass M + Δm is at rest and decays into two daughter nuclei of equal mass $\frac{M}{2}$ each. Speed of light is c.

3. The speed of daughter nuclei is :-

(1) $c\sqrt{\frac{\Delta m}{M+\Delta m}}$ (2) $c\frac{\Delta m}{M+\Delta m}$ (3) $c\sqrt{\frac{2\Delta m}{M}}$ (4) $c\sqrt{\frac{\Delta m}{M}}$

[AIEEE-2010]
MP0278

4. The binding energy per nucleon for the parent nucleus is E_1 an that for the daughter nuclei is E_2. Then:-

(1) $E_1 = 2E_2$ (2) $E_2 = 2E_1$ (3) $E_1 > E_2$ (4) $E_2 > E_1$

[AIEEE - 2010]
MP0279

5. A radioactive nucleus (initial mass number A and atomic number Z) emits 3 α-particles and 2 positrons. The ratio of number of neutrons to that of protons in the final nucleus will be:-

(1) $\frac{A-Z-4}{Z-2}$ (2) $\frac{A-Z-8}{Z-4}$ (3) $\frac{A-Z-4}{Z-8}$ (4) $\frac{A-Z-12}{Z-4}$

[AIEEE - 2010]
MP0280

6. The half life of a radioactive substance is 20 minutes. The approximate time interval $(t_2 - t_1)$ between the time t_2 when $\frac{2}{3}$ of it has decayed and time t_1 when $\frac{1}{3}$ of it had decayed is :-

(1) 20 min (2) 28 min (3) 7 min (4) 14 min

[AIEEE - 2011]
MP0281

7. 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 $5m_1(6m_1 = M + m_N)$, 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:-

(1) 25 λ (2) 5λ (3) $\frac{\lambda}{5}$ (4) λ

[AIEEE - 2011]
MP0282

8. **Statement-1:** A nucleus having energy E_1 decays be β^- emission to daughter nucleus having energy E_2, but the β^- rays are emitted with a continuous energy spectrum having end point energy $E_1 – E_2$.

Statement-2: To conserve energy and momentum in β-decay at least three particles must take part in the transformation.

(1) Statement-1 is incorrect, statement-2 is correct
(2) Statement-1 is correct, statement-2 is incorrect
(3) Statement-1 is correct, statement-2 correct; statement-2 is the correct explanation of statement-1
(4) Statement-1 is correct, statement-2 is correct; statement -2 is not the correct explanation of statement-1.

[AIEEE - 2011]
MP0283

9. Assume that a neutron breaks into a proton and an electron. The energy released during this process is :

(Mass of neutron = 1.6725×10^{-27} kg

Mass of proton = 1.6725×10^{-27} kg

Mass of electron = 9×10^{-31} kg)

(1) 5.4 MeV (2) 0.73 MeV (3) 7.10 MeV (4) 6.30 MeV

[AIEEE - 2012]

MP0284

10. 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** ?

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

[JEE-Main-2014]

MP0285

11. 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:-

(1) 0.8 eV (2) 1.6 eV (3) 1.8 eV (4) 1.1 eV

[JEE-Main-2014]

MP0286

12. Half-lives of two radioactive elements A and B are 20 minutes and 40 minutes, respectively. Initially, the samples have equal number of nuclei. After 80 minutes , the ratio of decayed numbers of A and B nuclei will be :-

(1) 5 : 4 (2) 1 : 16 (3) 4 : 1 (4) 1 : 4

[JEE-Main-2016]

MP0287

13. A radioactive nucleus A with a half life T, decays into a nucleus B. At t = 0, there is no nucleus B. At sometime t, the ratio of the number of B to that of A is 0.3. Then, t is given by :

(1) $t = T\log(1.3)$ (2) $t = \dfrac{T}{\log(1.3)}$ (3) $t = \dfrac{T}{2}\dfrac{\log 2}{\log 1.3}$ (4) $t = T\dfrac{\log 1.3}{\log 2}$

[JEE-Main-2017]

MP0288

14. An electron from various excited states of hydrogen atom emit radiation to come to the ground state. Let λ_n, λ_g be the de Broglie wavelength of the electron in the nth state and the ground state respectively. Let Λ_n be the wavelength of the emitted photon in the transition from the nth state to the ground state. For large n, (A, B are constants)

(1) $\Lambda_n \approx A + B\lambda_n$ (2) $\Lambda_n^2 \approx A + B\lambda_n^2$ (3) $\Lambda_n^2 \approx \lambda$ (4) $\Lambda_n \approx A + \dfrac{B}{\lambda_n^2}$

[JEE-Main-2018]

MP0289

SELECTED PROBLEMS FROM JEE-MAINS ONLINE PAPERS

15. Two radioactive substances A and B have decay constants 5λ and λ respectively. At t = 0, a sample has the same number of the two nuclei. The time taken for the ratio of the number of nuclei to become $\left(\frac{1}{e}\right)^2$ will be : **[JEE Main-2019_April]**

(1) $1 / 4\lambda$ (2) $1 / \lambda$ (3) $1 / 2\lambda$ (4) $2 / \lambda$

MP0379

16. Half lives of two radioactive nuclei A and B are 10 minutes and 20 minutes, respectively. If, initially a sample has equal number of nuclei, then after 60 minutes, the ratio of decayed numbers of nuclei A and B will be : **[JEE Main-2019_April]**

(1) 9 : 8 (2) 1 : 8 (3) 8 : 1 (4) 3 : 8

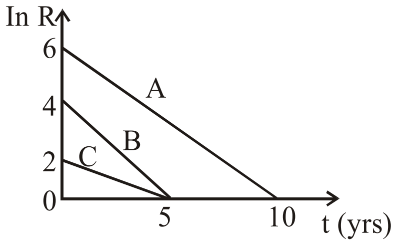
MP0380

17. In a reactor, 2 kg of $_{92}U^{235}$ fuel is fully used up in 30 days. The energy released per fission is 200 MeV. Given that the Avogadro number, $N = 6.023 \times 10^{26}$ per kilo mole and $1\ eV = 1.6 \times 10^{-19}$ J. The power output of the reactor is close to : **[JEE Main-2020_Sep]**

(1) 125 MW (2) 60 MW (3) 35 MW (4) 54 MW

MP0381

18. Activities of three radioactive substances A, B and C are represented by the curves A, B and C, in the figure. Then their half-lives $T_{\frac{1}{2}}(A) : T_{\frac{1}{2}}(B) : T_{\frac{1}{2}}(C)$ are in the ratio : **[JEE Main-2020_Sep]**



(1) 3 : 2 : 1 (2) 4 : 3 : 1 (3) 2 : 1 : 3 (4) 2 : 1 : 1

MP0382

19. You are given that Mass of $^7_3Li = 7.0160$ u, Mass of $^4_2He = 4.0026$ u and Mass of $^1_1H = 1.0079$ u. When 20 g of ^7_3Li is converted into ^4_2He by proton capture, the energy liberated, (in kWh), is: [Mass of nudeon = 1 GeV/c^2] **[JEE Main-2020_Sep]**

(1) 8×10^6 (2) 1.33×10^6 (3) 6.82×10^5 (4) 4.5×10^5

MP0383

20. Given the masses of various atomic particles $m_p = 1.0072u$, $m_n = 1.0087u$, $m_e = 0.000548u$, $m_{\bar{\nu}} = 0$, $m_d = 2.0141u$, where p ≡ proton, n ≡ neutron, e ≡ electron, $\bar{\nu}$ ≡ antineutrino and d ≡ deuteron. Which of the following process is allowed by momentum and energy conservation ? **[JEE Main-2020_Sep]**

(1) $n + p \rightarrow d + \gamma$
(2) $e^+ + e^- \rightarrow \gamma$
(3) $n + n \rightarrow$ deuterium atom (electron bound to the nucleus)
(4) $p \rightarrow n + e^+ + \bar{\nu}$

MP0384

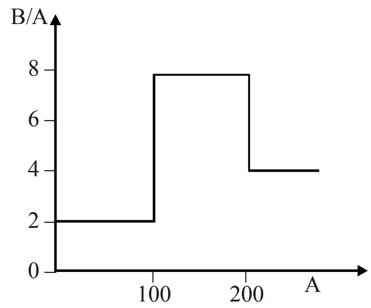
21. Find the bindng energy per nucleon for $^{120}_{50}Sn$. Mass of proton $m_p = 1.00783$ U, mass of neutron $m_n = 1.00867$ U and mass of tin nucleus $m_{Sn} = 119.902199$ U. (take 1U = 931 MeV) **[JEE Main-2020_Sep]**

(1) 8.5 MeV (2) 7.5 MeV (3) 8.0 MeV (4) 9.0 MeV

MP0385

EXERCISE - JA

1. Assume that the nuclear binding energy per nucleon (B/A) versus mass number (A) is as shown in the figure. Use this plot to choose the correct choice(s) given below : **[JEE 2008]**



(A) Fusion of two nuclei with mass numbers lying in the range of $1 < A < 50$ will release energy

(B) Fusion of two nuclei with mass numbers lying in the range of $51 < A < 100$ will release energy

(C) Fission of a nucleus lying in the mass range of $100 < A < 200$ will release energy when broken into two equal fragments

(D) Fission of a nucleus lying in the mass range of $200 < A < 260$ will release energy when broken into two equal fragments

MP0290

2. A radioactive sample S1 having an activity of 5μCi has twice the number of nuclei as another sample S2 which has an activity of 10μCi. The half lives of S1 and S2 can be : **[JEE 2008]**

(A) 20 years and 5 years, respectively (B) 20 years and 10 years, respectively

(C) 10 years each (D) 5 years each

MP0291

Paragraph for Question Nos. 3 to 5

Scientists are working hard to develop nuclear fusion reactor. Nuclei of heavy hydrogen, ${}_1^2H$, known as deuteron and denoted by D, can be thought of as a candidate for fusion reactor. The D-D reaction is ${}_1^2H + {}_1^2H \rightarrow {}_2^3He + n + \text{energy}$. In the core of fusion reactor, a gas of heavy hydrogen is fully ionized into deuteron nuclei and electrons. This collection of ${}_1^2H$ nuclei and electrons is known as plasma. The nuclei move randomly in the reactor core and occasionally come close enough for nuclear fusion to take place. Usually, the temperatures in the reactor core are too high and no material wall can be used to confine the plasma. Special techniques are used which confine the plasma for a time t_0 before the particles fly away from the core. If n is the density (number/volume) of deuterons, the product nt_0 is called Lawson number. In one of the criteria, a reactor is termed successful if Lawson number is greater than 5×10^{14} s/cm^3. It may be helpful to use the following :

Boltzmann constant $k = 8.6 \times 10^{-5}$ eV/K ; $\dfrac{e^2}{4\pi\varepsilon_0} = 1.44 \times 10^{-9}$ eVm.

3. In the core of nuclear fusion reactor, the gas becomes plasma because of **[JEE-2009]**

(A) strong nuclear force acting between the deuterons

(B) Coulomb force acting between the deuterons

(C) Coulomb force acting between deuteron-electron pairs

(D) the high temperature maintained inside the reactor core

MP0292

4. Assume that two deuteron nuclei in the core of fusion reactor at temperature T are moving towards each other, each with kinetic energy 1.5 kT, when the separation between them is large enough to neglect Coulomb potential energy. Also neglect any interaction from other particles in the core. The minimum temperature T required for them to reach a separation of 4×10^{-15} m is in the range

(A) $1.0 \times 10^9\ K < T < 2.0 \times 10^9\ K$ (B) $2.0 \times 10^9\ K < T < 3.0 \times 10^9\ K$

(C) $3.0 \times 10^9\ K < T < 4.0 \times 10^9\ K$ (D) $4.0 \times 10^9\ K < T < 5.0 \times 10^9\ K$

[JEE-2009]
MP0292

5. Results of calculations for four different designs of a fusion reactor using D-D reaction are given below. Which of these is most promising based on Lawson criterion?

(A) deuteron density = $2.0 \times 10^{12}\ cm^{-3}$, confinement time = 5.0×10^{-3} s

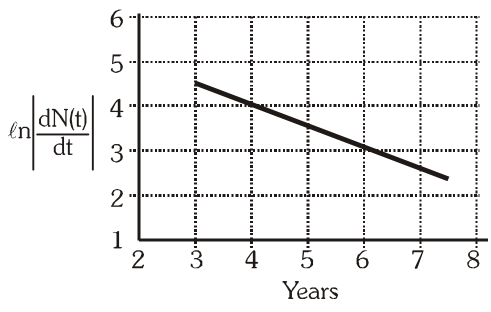
(B) deuteron density = $8.0 \times 10^{14}\ cm^{-3}$, confinement time = 9.0×10^{-1} s

(C) deuteron density = $4.0 \times 10^{23}\ cm^{-3}$, confinement time = 1.0×10^{-11} s

(D) deuteron density = $1.0 \times 10^{24}\ cm^{-3}$, confinement time = 4.0×10^{-12} s

[JEE-2009]
MP0292

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



MP0293

7. The activity of a freshly prepared radioactive sample is 10^{10} disintegrations per second, whose mean life is 10^9 s. The mass of an atom of this radioisotope is 10^{-25} kg. The mass (in mg) of the radioactive sample is **[JEE-2011]**

MP0294

Paragraph for Questions 8 and 9

The β-decay process, discovered around 1900, is basically the decay of a neutron (n). In the laboratory, a proton (p) and an electron (e^-) are observed as the decay products of the neutron. Therefore, considering the decay of a neutron as a two-body decay process, it was predicted theoretically that the kinetic energy of the electron should be a constant. But experimentally, it was observed that the electron kinetic energy has a continuous spectrum. Considering a three-body decay process, i.e. n→ p + e^- + $\vec{v}_e$, around 1930, Pauli explained the observed electron energy spectrum. Assuming the anti-neutrino $(\vec{v}_e)$ to be massless and possessing negligible energy, and the neutron to be at rest, momentum and energy conservation principles are applied. From this calculation, the maximum kinetic energy of the electron is 0.8×10^6 eV. The kinetic energy carried by the proton is only the recoil energy.

8. If the anti-neutrino had a mass of 3 eV/c^2 (where c is the speed of light) instead of zero mass, what should be the range of the kinetic energy, K, of the electron?

(A) $0 \le K \le 0.8 \times 10^6 eV$ (B) $3.0eV \le K \le 0.8 \times 10^6 eV$

(C) $3.0eV \le K < 0.8 \times 10^6 eV$ (D) $0 \le K < 0.8 \times 10^6 eV$

[JEE 2012]

MP0295

9. What is the maximum energy of the anti-neutrino?

(A) zero (B) much less than 0.8×10^6 eV

(C) Nearly 0.8×10^6 eV (D) Much larger than 0.8×10^6 eV

[JEE 2012]

MP0295

10. A freshly prepared sample of a radioisotope of half-life 1386 s has activity 10^3 distintegrations per second. Given that $\ell n\ 2 = 0.693$, the fraction of the initial number of nuclei (expressed in nearest integer percentage) that will decay in the first 80 s after preparation of the sample is.

[JEE Advance-2013]

MP0296

Paragraph for Questions 11 and 12

The mass of a nucleus ${}^A_Z X$ is less than the sum of the masses of (A – Z) number of neutrons and Z number of protons in the nucleus. The energy equivalent to the corresponding mass difference is known as the binding energy of the nucleus. A heavy nucleus of mass M can break into two light nuclei of masses m_1 and m_2 only if $(m_1 + m_2) < M$. Also two light nuclei of masses m_3 and m_4 can undergo complete fusion and form a heavy nucleus of mass M' only if $(m_3 + m_4) > M'$. The masses of some neutral atoms are given in the table below :- **[JEE Advance-2013]**

${}^1_1H$	1.007825 u	${}^2_1H$	2.014102 u	${}^3_1H$	3.016050 u	${}^4_2He$	4.002603 u
${}^6_3Li$	6.015123 u	${}^7_3Li$	7.016004 u	${}^{70}_{30}Zn$	69.925325 u	${}^{82}_{34}Se$	81.916709 u
${}^{152}_{64}Gd$	151.919803 u	${}^{206}_{82}Pb$	205.974455 u	${}^{209}_{83}Bi$	208.980388 u	${}^{210}_{84}Po$	209.982876 u

(1u = 932 MeV/c^2)

11. The kinetic energy (in keV) of the alpha particle, when the nucleus ${}^{210}_{84}Po$ at rest undergoes alpha decay, is :-

(A) 5319 (B) 5422 (C) 5707 (D) 5818

MP0297

12. The correct statement is :-

(A) The nucleus ${}^{6}_{3}Li$ can emit an alpha particle

(B) The nucleus ${}^{210}_{84}Po$ can emit a proton

(C) Deuteron and alpha particle can undergo complete fusion

(D) The nuclei ${}^{70}_{30}Zn$ and ${}^{82}_{34}Se$ can undergo complete fusion

MP0297

13. Match List I of the nuclear processes with List II containing parent nucleus and one of the end products of each process and then select the correct answer using the codes given below the lists:

[JEE Advance-2013]

	List I		List II
P.	Alpha decay	1.	${}^{15}_{8}O \rightarrow {}^{15}_{7}N + ...$
Q.	β^{+} decay	2.	${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + ...$
R.	Fission	3.	${}^{185}_{83}Bi \rightarrow {}^{184}_{82}Pb + ...$
S.	Proton emission	4.	${}^{239}_{94}Pu \rightarrow {}^{140}_{57}La + ...$

Codes :

	P	Q	R	S
(A)	4	2	1	3
(B)	1	3	2	4
(C)	2	1	4	3
(D)	4	3	2	1

MP0298

14. If λ_{Cu} is the wavelength of K_α X-ray line of copper (atomic number 29) and λ_{Mo} is the wavelength of the K_α X-ray line of molybdenum (atomic number 42), then the ratio $\frac{\lambda_{Cu}}{\lambda_{Mo}}$ is close to :-

(A) 1.99 (B) 2.14 (C) 0.50 (D) 0.48

[JEE Advance-2014]

MP0299

15. A metal surface is illuminated by light of two different wavelength 248 nm and 310 nm. The maximum speeds of the photoelectrons corresponding to these wavelengths are u_1 and u_2, respectively. If the ratio $u_1 : u_2 = 2 : 1$ and hc = 1240 eV nm, the work function of the metal is nearly :-

(A) 3.7 eV (B) 3.2 eV (C) 2.8 eV (D) 2.5 eV

[JEE Advance-2014]

MP0300

16. A nuclear power plant supplying electrical power to a village uses a radioactive material of half life T years as the fuel. The amount of fuel at the beginning is such that the total power requirement of the village is 12.5% of the electrical power available from the plant at that time. If the plant is able to meet the total power needs of the village for a maximum period of nT years, then the value of n is.

[JEE Advance-2015]

MP0301

17. Match the nuclear processes given in column-I with the appropriate option(s) in column-II.

[JEE Advance-2015]

Column-I		**Column-II**	
(A)	Nuclear fusion	(P)	Absorption of thermal neutrons by $^{235}_{92}U$
(B)	Fission in a nuclear reactor	(Q)	$^{60}_{27}Co$ nucleus
(C)	β-decay	(R)	Energy production in stars via hydrogen conversion to helium
(D)	γ-ray emission	(S)	Heavy water
		(T)	Neutrino emission

MP0302

18. For a radioactive material, its activity A and rate of change of its activity R are defined as $A = -\frac{dN}{dt}$ and $R = -\frac{dA}{dt}$, where N(t) is the number of nuclei at time t. Two radioactive sources P (mean life τ) and Q (mean life 2τ) have the same activity at t = 0. Their rates of change of activities at t = 2τ are R_P and R_Q, respectively. If $\frac{R_P}{R_Q} = \frac{n}{e}$, then the value of n is :

[JEE Advance-2015]
MP0303

19. A fission reaction is given by $^{236}_{92}U \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + x + y$, where x and y are two particles. Considering $^{236}_{92}U$ to be at rest, the kinetic energies of the products are denoted by $K_{Xe}, K_{sr}, K_x(2MeV)$ and K_y(2MeV), respectively. Let the binding energies per nucleon of $^{236}_{92}U$, $^{140}_{54}Xe$ and $^{94}_{38}Sr$ be 7.5 MeV, 8.5 MeV and 8.5 MeV, respectively. Considering different conservation laws, the correct options(s) is (are) :- **[JEE Advance-2015]**

(A) x = n, y = n, K_{sr} = 129 MeV, K_{xe} = 86 MeV
(B) x = p, y = e^-, K_{Sr} = 129 MeV, K_{xe} = 86 MeV
(C) x = p, y = n, K_{Sr} = 129 MeV, K_{xe} = 86 MeV
(D) x = n, y = n, K_{Sr} = 86 MeV, K_{xe} = 129 MeV

MP0304

20. The isotope $_5^{12}B$ having a mass 12.014 u undergoes β-decay to $_6^{12}C$. $_6^{12}C$ has an excited state of the nucleus ($_6^{12}C^*$) at 4.041 MeV above its ground state. If $_5^{12}B$ decays to $_6^{12}C^*$, the maximum kinetic energy of the β-particle in units of MeV is (1u = 931.5 MeV/c^2, where c is the speed of light in vacuum). **[JEE Advance-2016]**

MP0305

21. The electrostatic energy of Z protons uniformly distributed throughout a spherical nucleus of radius R is given by $E = \frac{3}{5}\frac{Z(Z-1)e^2}{4\pi\varepsilon_0 R}$ **[JEE Advance-2016]**

The measured masses of the neutron, ${}_1^1H$, ${}_7^{15}N$ and ${}_8^{15}O$ are 1.008665 u, 1.007825 u, 15.000109 u and 15.003065 u respectively. Given that the radii of both the ${}_7^{15}N$ and ${}_8^{15}O$ nuclei are same, 1u = 931.5 MeV/c^2 (c is the speed of light) and $\frac{e^2}{(4\pi\varepsilon_0)}$ = 1.44 MeV fm. Assuming that the difference between the binding energies of ${}_7^{15}N$ and ${}_8^{15}O$ is purely due to the electrostatic energy, the radius of either of the nuclei is (1fm = 10^{-15}m)

(A) 2.85 fm (B) 3.03 fm (C) 3.42 fm (D) 3.80 fm

MP0306

22. An accident in a nuclear laboratory resulted in deposition of a certain amount of radioactive material of half-life 18 days inside the laboratory. Tests revealed that the radiation was 64 times more than the permissible level required for safe operation of the laboratory. What is the minimum number of days after which the laboratory can be considered safe for use? **[JEE Advance-2016]**

(A) 64 (B) 90 (C) 108 (D) 120

MP0307

23. ^{131}I is an isotope of Iodine that β decays to an isotope of Xenon with a half-life of 8 days. A small amount of a serum labelled with ^{131}I is injected into the blood of a person. The activity of the amount of ^{131}I injected was 2.4×10^5 Becquerel (Bq). It is known that the injected serum will get distributed uniformly in the blood stream in less than half an hour. After 11.5 hours, 2.5 ml of blood is drawn from the person's body, and gives an activity of 115 Bq. The total volume of blood in the person's body, in liters is approximately (you may use $e^x \approx 1 + x$ for $|x| << 1$ and $\ln 2 \approx 0.7$).

[JEE Advance-2017]

MP0308

24. In a radioactive decay chain, ${}_{90}^{232}Th$ nucleus decays to ${}_{82}^{212}Pb$ nucleus. Let N_α and N_β be the number of α and β^- particles, respectively, emitted in this decay process. Which of the following statements is (are) true ?

(A) $N_\alpha = 5$ (B) $N_\alpha = 6$ (C) $N_\beta = 2$ (D) $N_\beta = 4$

[JEE Advance-2018]

MP0309

25. Suppose a ${}_{88}^{226}Ra$ nucleus at rest and in ground state undergoes α-decay to a ${}_{86}^{222}Rn$ nucleus in its excited state. The kinetic energy of the emitted α particle is found to be 4.44 MeV. ${}_{86}^{222}Rn$ nucleus then goes to its ground state by γ-decay. The energy of the emitted γ-photon is _______ keV, [Given: atomic mass of ${}_{88}^{226}Ra = 226.005u$, atomic mass of ${}_{86}^{222}Rn = 222.000u$, atomic mass of α particle = 4.000u, 1u = 931 MeV/c^2, c is speed of the light] **[JEE Advanced-2019]**

MP0310

ANSWER KEY

EXERCISE (S-1)

1. Ans. $8/3\times10^{18}$ sec **2. Ans.** 28 MeV **3. Ans.** v = 1.546×10^{18} Hz; Z = 26

4. Ans. 4.87 MeV **5. Ans.** 6.04×10^{9} yrs **6. Ans.** $t=\left(\frac{\ln 5}{\ln 2}\right)\tau$

EXERCISE (S-2)

1. Ans. 1.7×10^{10} years **2. Ans.** 5196 yrs **3. Ans.** $v=u\lambda t$

4. Ans. $\Delta T=\dfrac{0.2E_0\left[\alpha t-\frac{\alpha}{\lambda}(1-e^{-\lambda t})\right]}{mS}$ **5. Ans.** $\cong 33.298\ \mu W$

6. Ans. 6 litre **7. Ans.** 2.4×10^{-12} m **8. Ans.** 9.00×10^{6}

9. Ans. ($T_{1/2}$ = 10.8 sec) **10. Ans.** $1.75n=N_0(1-e^{-4\lambda})$, 6.95 sec, $\dfrac{2}{\ln\left(\frac{4}{3}\right)}$

11. Ans. 0.259

EXERCISE (O-1)

SINGLE CORRECT TYPE QUESTIONS

1. Ans. (D) **2. Ans. (C)** **3. Ans. (A)** **4. Ans. (A)** **5. Ans. (D)** **6. Ans. (A)**
7. Ans. (B) **8. Ans. (A)** **9. Ans. (B)** **10. Ans. (D)** **11. Ans. (B)** **12. Ans. (B)**
13. Ans. (C) **14. Ans. (C)** **15. Ans. (A)** **16. Ans. (B)** **17. Ans. (C)** **18. Ans. (B)**
19. Ans. (C) **20. Ans. (B)** **21. Ans. (A)** **22. Ans. (D)** **23. Ans. (D)** **24. Ans. (C)**
25. Ans. (B) **26. Ans. (B)** **27. Ans. (B)** **28. Ans. (C)** **29. Ans. (A)** **30. Ans. (C)**
31. Ans. (C) **32. Ans. (C)** **33. Ans. (A)** **34. Ans. (B)** **35. Ans. (C)** **36. Ans. (C)**
37. Ans. (B) **38. Ans. (B)** **39. Ans. (C)**

MATRIX MATCH TYPE QUESTION

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

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

EXERCISE (O-2)

1. Ans. (B) **2. Ans. (B)** **3. Ans. (C)** **4. Ans. (D)**
5. Ans. (C) **6. Ans. (C)** **7. Ans. (B)** **8. Ans. (B)**
9. Ans. (C) **10. Ans. (B)** **11. Ans. (C)** **12. Ans. (A)**
13. Ans. (E) **14. Ans. (B)** **15. Ans. (C)** **16. Ans. (D)**
17. Ans. (C) **18. Ans. (A, B, D)** **19. Ans. (A, C)** **20. Ans. (C, D)**
21. Ans. (A, C) **22. Ans. (A, D)** **23. Ans. (B, C)** **24. Ans. (A, C, D)**
25. Ans. (A, B, C) **26. Ans. (A, B, C)** **27. Ans. (C, D)**
28. Ans. (i) A, (ii) E (iii) F (iv) C

EXERCISE - JM

1. Ans. (4)	2. Ans. (3)	3. Ans. (3)	4. Ans. (4)	5. Ans. (3)	6. Ans. (1)
7. Ans. (4)	8. Ans. (3)	9. Ans. (Bonus)	10. Ans. (1)	11. Ans. (4)	12. Ans. (1)
13. Ans. (4)	14. Ans. (4)				

SELECTED PROBLEMS FROM JEE-MAINS ONLINE PAPERS

15. Ans. (3)	16. Ans. (1)	17. Ans. (2)	18. Ans. (3)	19. Ans. (2)	20. Ans. (1)
21. Ans. (1)					

EXERCISE - JA

1. Ans. (B, D)	2. Ans. (A)	3. Ans. (D)	4. Ans. (A)
5. Ans. (B)	6. Ans. (8)	7. Ans. (1)	8. Ans. (D)
9. Ans. (C)	10. Ans. 4	11. Ans. (A)	12. Ans. (C)
13. Ans. (C)	14. Ans. (B)	15. Ans. (A)	16. Ans. 3
17. Ans. (A)-R or R,T; (B)-P & S; (C)-Q & T; (D)-R			18. Ans. 2
19. Ans. (A)	20. Ans. 9	21. Ans. (C)	22. Ans. (C)
23. Ans. 5	24. Ans. (A,C)	25. Ans. (135.00)	

ALLEN CAREER INSTITUTE KOTA (RAJASTHAN)

path to success

Chapter Contents 03

ERROR IN MEASUREMENTS & INSTRUMENTS

Important Notes

KEY CONCEPTS

ERRORS

Whenever an experiment is performed, two kinds of errors can appear in the measured quantity.

(1) random and (2) systematic errors.

1. Random errors appear randomly because of operator, fluctuations in external conditions and variability of measuring instruments. The effect of random error can be some what reduced by taking the average of measured values. Random errors have no fixed sign or size.

2. Systematic errors occur due to error in the procedure, or miscalibration of the instrument etc. Such errors have same size and sign for all the measurements. Such errors can be determined.

   A measurement with relatively small random error is said to have high precision. A measurement with small random error and small systematic error is said to have high accuracy.

   The experimental error [uncertainty] can be expressed in several standard ways.

   Error limits $Q \pm \Delta Q$ is the measured quantity and ΔQ is the magnitude of its limit of error. This expresses the experimenter's judgment that the 'true' value of Q lies between $Q - \Delta Q$ and $Q + \Delta Q$. This entire interval within which the measurement lies is called the range of error. Random errors are expressed in this form.

Absolute Error

Error may be expressed as absolute measures, giving the size of the error in a quantity in the same units as the quantity itself.

Least Count Error :– If the instrument has known least count, the absolute error is taken to be equal to the least count unless otherwise stated.

Relative (or Fractional) Error

Error may be expressed as relative measures, giving the ratio of the quantity's error to the quantity itself. In general,

$$\text{relative error} = \frac{\textit{absolute error in a measurement}}{\textit{size of the measurement}}$$

We should know the error in the measurement because these errors propagate through the calculations to produce errors in results.

A. ***Systematic errors*** **:**

They have a known sign. The systematic error is removed before beginning calculations. Bench error and zero error are examples of systematic error.

B. ***Random error* :**

They have unknown sign. Thus they are represented in the form A ± a.

Here we are only concerned with *limits of error*. We must assume a "worst-case" combination. In the case of substraction, A – B, the worst-case deviation of the answer occurs when the errors are either + a and – b or – a and + b. In either case, the maximum error will be (a + b).

For example in the experiment on finding the focal length of a convex lens, the object distance (u) is found by subtracting the positions of the object needle and the lens. If the optical bench has a least count of 1 mm, the error in each position will be 0.5 mm. So, the error in the value of u will be 1 mm.

1. ***Addition and subtraction rule* :** The absolute random errors add.

   Thus if $R = A + B$, $r = a + b$ and if $R = A - B$, $r = a + b$

2. ***Product and quotient rule* :** The relative random errors add.

   Thus if $R = AB$, $\frac{r}{R} = \frac{a}{A} + \frac{b}{B}$ and if $R = \frac{A}{B}$, then also $\frac{r}{R} = \frac{a}{A} + \frac{b}{B}$

3. ***Power rule* :** When a quantity Q is raised to a power P, the relative error in the result is P times the relative error in Q. This also holds for negative powers. If $R = Q^P$, $\frac{r}{R} = P \times \frac{q}{Q}$

4. The quotient rule is not applicable if the numerator and denominator are dependent on each other.

   e.g if $R = \frac{XY}{X+Y}$. We cannot apply quotient rule to find the error in R. Instead we write the equation as follows $\frac{1}{R} = \frac{1}{X} + \frac{1}{Y}$. Differentiating both the sides, we get $-\frac{dR}{R^2} = -\frac{dX}{X^2} - \frac{dY}{Y^2}$.

   Thus $\frac{r}{R^2} = \frac{x}{X^2} + \frac{y}{Y^2}$

Examples

A student finds the constant acceleration of a slowly moving object with a stopwatch. The equation used is $S = (1/2)AT^2$. The time is measured with a stopwatch, the distance, S with a meter stick. What is the acceleration and its estimated error?

$S = 2 \pm 0.005$ meter. $T = 4.2 \pm 0.2$ second.

Sol : We use capital letters for quantities, lower case for errors. Solve the equation for the result, a. $A = 2S/T^2$. Its random-error equation is $\frac{a}{A} = 2\frac{t}{T} + \frac{s}{S}$. Thus $A = 0.23 \pm 0.02$ m/s^2.

SIGNIFICANT DIGITS

Significant figures are digits that are statistically significant. There are two kinds of values in science:

1. Measured Values 2. Computed Values

The way that we identify the proper number of significant figures in science are different for these two types.

MEASURED VALUES

Identifying a measured value with the correct number of significant digits requires that the instrument's calibration be taken into consideration. The last significant digit in a measured value will be the first estimated position. For example, a metric ruler is calibrated with numbered calibrations equal to 1 cm. In addition, there will be ten unnumbered calibration marks between each numbered position. (each equal to 0.1 cm). Then one could with a little practice estimate between each of those marking. (each equal to 0.05 cm). That first estimated position would be the last significant digit reported in the measured value. Let's say that we were measuring the length of a tube, and it extended past the fourteenth numbered calibration half way between the third and fourth unnumbered mark. The metric ruler was a meter stick with 100 numbered calibrations. The reported measured length would be 14.35 cm. Here the total number of significant digits will be 4.

COMPUTED VALUE

The other type of value is a computed value. The proper number of significant figures that a computed value should have is decided by a set of conventional rules. However before we get to those rules for computed values we have to consider how to determine how many significant digits are indicated in the numbers being used in the math computation.

A. Rules for determining the number of significant digits in number with indicated decimals.

1. All nonzero digits (1-9) are to be counted as significant.
2. Zeros that have any nonzero digits anywhere to the LEFT of them are considered significant zeros.
3. All other zeros not covered in rule (2) above are NOT be considered significant digits.

For example : 0.0040000

The 4 is obviously to be counted significant (Rule-1), but what about the zeros? The first three zeros would not be considered significant since they have no nonzero digits anywhere to their left (Rule-3). The last four zeros would all be considered significant since each of them has the nonzero digit 4 to their left (Rule-2). Therefore the number has a total of five significant digits.

Here is another example : 120.00420

The digit 1, 2, 4 and 2 are all considered significant (Rule-1). All zeros are considered significant since they have non-zero digits somewhere to their left (Rule-2). So there are a total of eight significant digits. If in the question, we are given a number like 100, we will treat that the number has only one significant digit by convention.

B. Determining the number of significant digits if number is not having an indicated decimal.

The decimal indicated in a number tells us to what position of estimation the number has been indicated. But what about 1,000,000?

Notice that there is no decimal indicated in the number. In other words, there is an ambiguity concerning the estimated position. This ambiguity can only be clarified by placing the number in exponential notation.

For example : If I write the number above in this manner.

1.00×10^6

I have indicated that the number has been recorded with three significant digits. On the other hand, if I write the same number as : 1.0000×10^6

I have identified the number to have 5 significant digits. Once the number has been expressed in exponential notation form then the digits that appear before the power of ten will all be considered significant. So for example : 2.0040×10^4 will have five significant digits. This means that unit conversion will not change the number of significant digits.

Thus 0.000010 km = 1.0 cm = 0.010 m = 1.0×10^{-2} m = 1.0×10^{-5} km

Rule for expressing proper number of significant digits in an answer from multiplication or division

For multiplication AND division there is the following rule for expressing a computed product or quotient with the proper number of significant digits.

The product or quotient will be reported as having as many significant digits as the number involved in the operation with the least number of significant digits.

For example : $0.000170 \times 100.40 = 0.017068$

The product could be expressed with no more that three significant digits since 0.000170 has only three significant digits, and 100.40 has five. So according to the rule the product answer could only be expressed with three significant digits. Thus the answer should be 0.0171 (after rounding off)

Another example : $2.000 \times 10^4 / 6.0 \times 10^{-3} = 0.33 \times 10^7$

The answer could be expressed with no more that two significant digits since the least digit number involved in the operation has two significant digits.

Sometimes this would required expressing the answer in exponential notation.

For example : $3.0 \times 800.0 = 2.4 \times 10^3$

The number 3.0 has two significant digits and then number 800.0 has four. The rule states that the answer can have no more than two digits expressed. However the answer as we can all see would be 2400. How do we express the answer 2400 while obeying the rules? The only way is to express the answer in exponential notation so 2400 could be expressed as : 2.4×10^3

Rule for expressing the correct number of significant digits in an addition or substraction :

The rule for expressing a sum or difference is considerably different than the one for multiplication of division. The sum or difference can be no more precise than the least precise number involved in the mathematical operation. Precision has to do with the number of positions to the RIGHT of the decimal. The more position to the right of the decimal, the more precise the number. So a sum or difference can have no more indicated positions to the right of the decimal as the number involved in the operation with the LEAST indicated positions to the right of its decimal.

For example : 160.45 + 6.732 = 167.18 (after rounding off)

The answer could be expressed only to two positions to the right of the decimal, since 160.45 is the least precise.

Another example : 45.621 + 4.3 – 6.41 = 43.5 (after rounding off)

The answer could be expressed only to one position to the right of the decimal, since the number 4.3 is the least precise number (i.e. having only one position to the right of its decimal). Notice we aren't really determining the total number of significant digits in the answer with this rule.

Rules for rounding off digits :

There are a set of conventional rules for rounding off.

1. Determine according to the rule what the last reported digit should be.
2. Consider the digit to the right of the last reported digit.
3. If the digit to the right of the last reported digit is less than 5 round it and all digits to its right off.
4. If the digit to the right of the last reported digit is greater than 5 round it and all digits to its right off and increased the last reported digit by one.
5. If the digit to the right of the last reported digit is a 5 followed by either no other digits or all zeros, round it and all digits to its right off and if the last reported digit is odd round up to the next even digit. If the last reported digit is even then leave it as is.

For example if we wish to round off the following number to 3 significant digits : 18.3682

The last reported digits would be the 3. The digit to its right is a 6 which is greater than 5. According to the Rule-4 above, the digit 3 is increased by one and the answer is : 18.4

Another example : Round off 4.565 to three significant digits.

The last reported digit would be the 6. The digit to the right is a 5 followed by nothing. Therefore according to Rule-5 above since the 6 is even it remains so and the answer would be 4.56.

EXPERIMENTS IN JEE-ADVANCED SYLLABUS

(i) Measurement of length

The simplest method measuring the length of a straight line is by means of a meter scale. But there exists some limitation in the accuracy of the result:

(i) the dividing lines have a finite thickness.

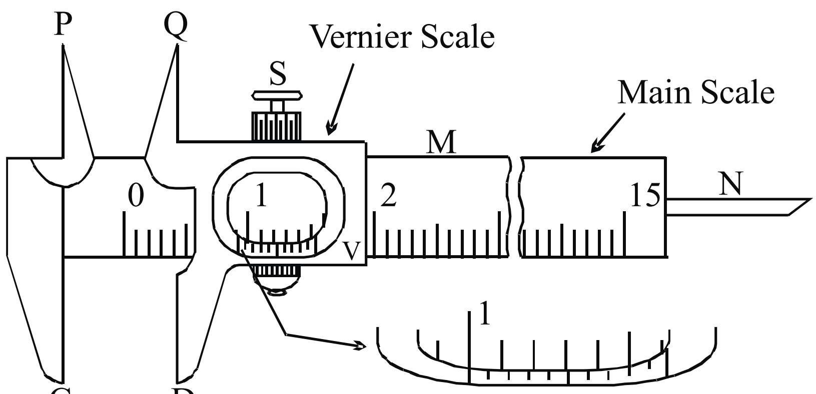
(ii) naked eye cannot correctly estimate less than 0.5 mm

For greater accuracy devices like

(a) Vernier callipers

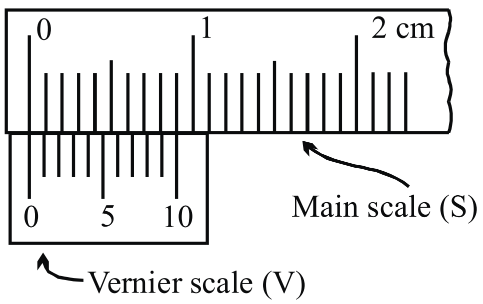
(b) micrometer scales (screw gauge) are used.

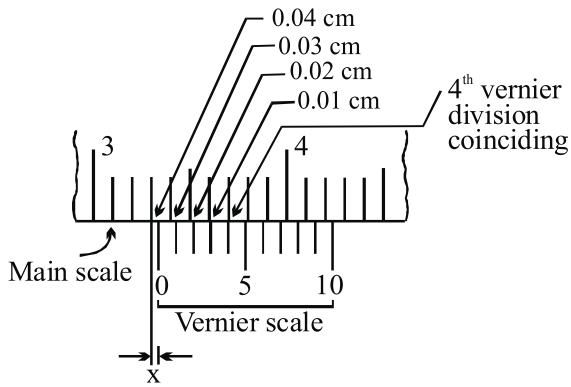
VERNIER CALLIPERS:



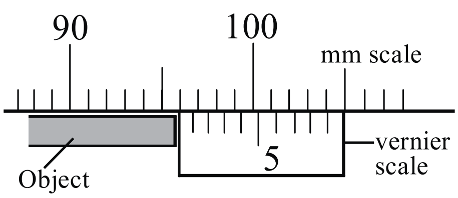
Vernier Callipers

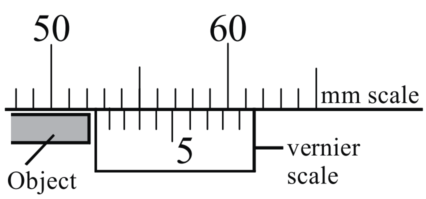
<u>Principle of Vernier</u>





Reading a vernier with 4th division coinciding





It consists of a main scale graduated in cm/mm over which an auxiliary scale (or Vernier scale) can slide along the length. The division of the Vernier scale being shorter than the divisions of the main scale.

Least count of Vernier Callipers

The least count or Vernier constant (v. c) is the minimum value of correct estimation of length without eye estimation. If N division of vernier coincides with (N-1) division of main scale, then

$$N\,(VS) = (N-1)\text{ ms} \quad \Rightarrow\ 1VS = \frac{N-1}{N}\text{ ms}$$

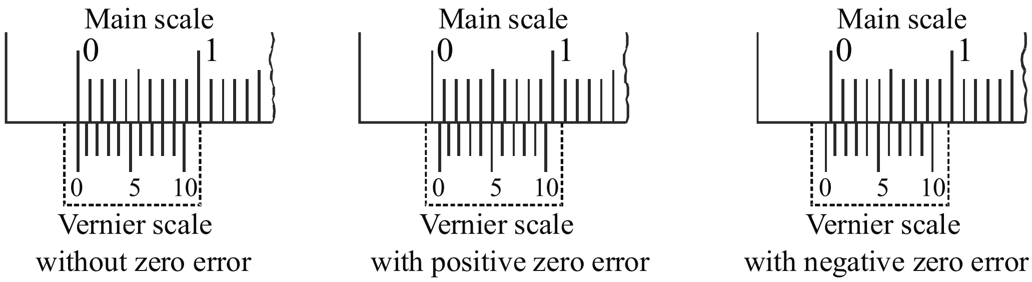
Vernier constant = 1 ms – 1 vs = $\left(1-\frac{N-1}{N}\right)\text{ms} = \frac{1\text{ms}}{N}$, which is equal to the value of the smallest division on the main scale divided by total number of divisions on the vernier scale.

Length as measured by Vernier Callipers

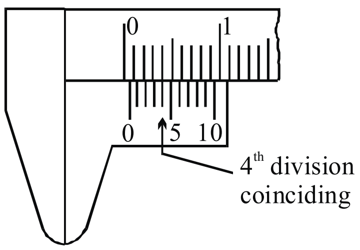
The formula for measuring the length is L = main scale reading + least count of vernier scale × Vernier scale division coinciding with a main scale division

Main scale reading is given by the zeroth division of the vernier scale as shown in the figure.

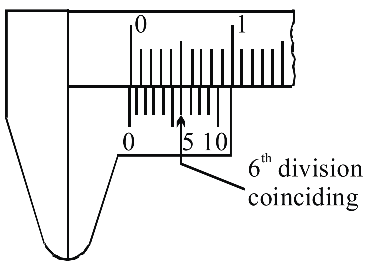
Zero error:



(i) (ii)



Positive zero error (+0.04 cm) and its correction



Negative zero error = (–0.04 cm) and its correction

If the zero marking of main scale and vernier callipers do not coincide, necessary correction has to be made for this error which is known as zero error of the instrument.

If the zero of the vernier scale is to the right of the zero of the main scale the zero error is said to be positive and the correction will be negative and vice versa.

The zero error is always subtracted from the reading to get the corrected value.

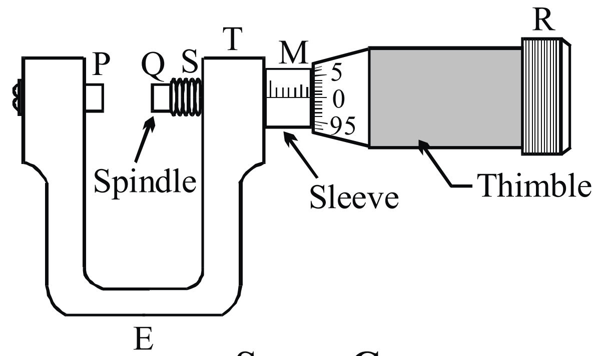
If the zero error is positive, its value is calculated as we take any normal reading. If the zero error negative (the zero of vernier scale lies to the left of the zero of main scale),

negative zero error = – [Total no. of vsd – vsd coinciding] × L.C.

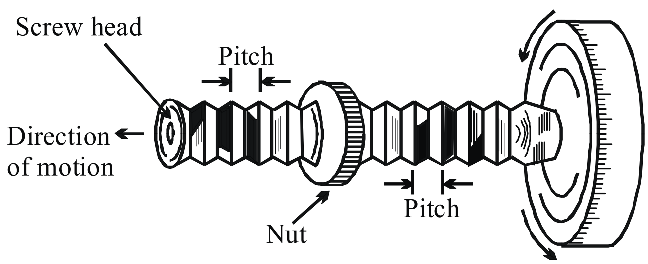
Do not try to read the main scale at the point where the lines match best. This has no meaning. Read from the vernier scale instead. Sometimes it is difficult to tell whether the best match of lines is for vernier marks 9, 0, or 1. Make your best estimate, but realize that the final result including the vernier must round off to the result you would choose if there was no vernier. If the mark is close to 3.20 on the main scale, but the vernier reading is 9, the length is 3.19 cm. If the mark is close to 3.2 on the main scale and the vernier is 1, the length is 3.21 cm.

SCREW GAUGE (OR MICROMETER SCREW)

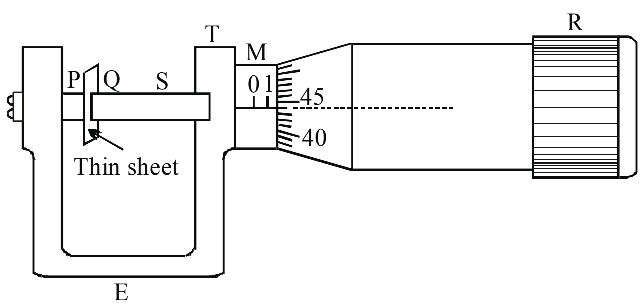
In general vernier callipers can measure accurately upto 0.01 em and for greater accuracy micrometer screw devices e.g. screw gauge, spherometer are used. These consist of accurately cut screw which can be moved in a closely fitting fixed nut by tuming it axially. The instrument is provided with two scales:

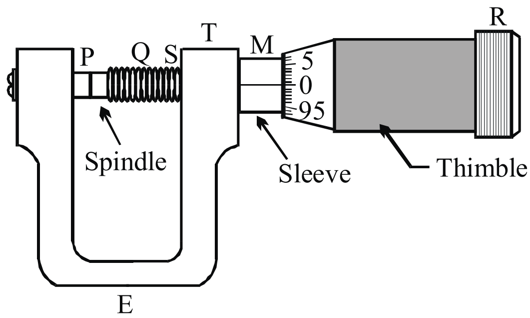


Screw Gauge

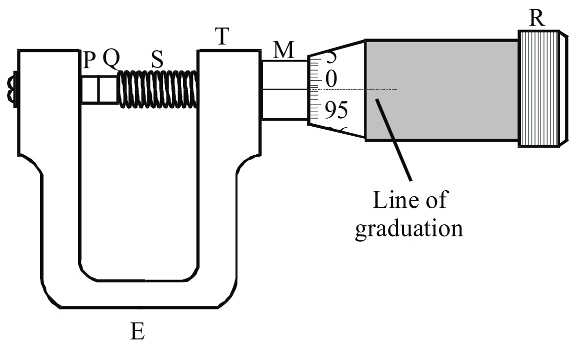


Principle of a micrometer

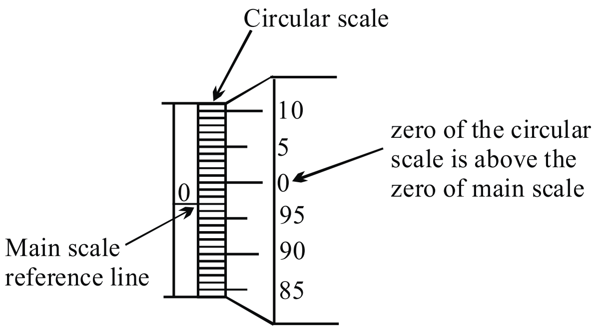


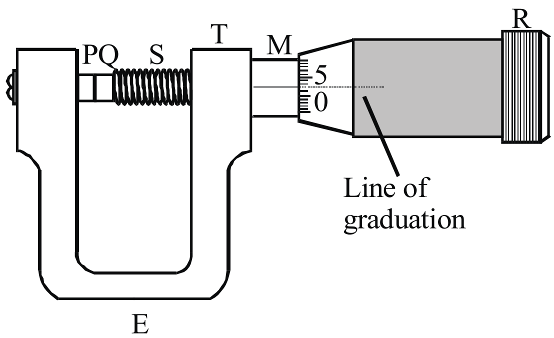


Screw gauge with no zero error

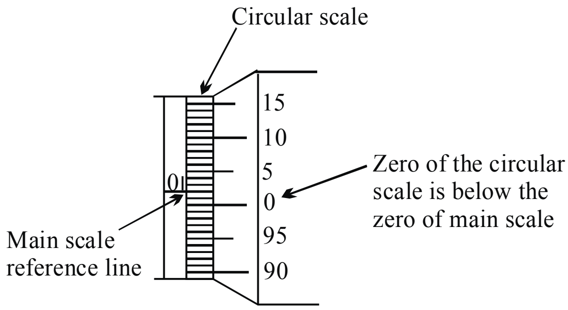


Negative zero error
(3 division error) i.e., - 0.003 cm





Positive zero error
(2 division error) i.e., + 0.002 cm



(i) The main scale or pitch scale M graduated along the axis of the screw.

(ii) The cap-scale or head scale H round the edge of the screw head.

Constants of the Screw Gauge

(a) **Pitch :** The translational motion of the screw is directly proportional to the total rotation of the head. The pitch of the instrument is the distance between two consecutive threads of the screw which is equal to the distance moved by the screw due to one complete rotation of the cap. Thus for 10 rotation of cap = 5 mm, then pitch = 0.5 mm

(b) **Least count :** In this case also, the minimum (or least) measurement (or count) of length is equal to one division on the head scale which is equal to pitch divided by the total cap divisions. Thus in the aforesaid Illustration:, if the total cap division is 100, then least count = 0.5mm/100 = 0.005 mm

(c) **Measurement of length by screw gauge :**

$L = n \times \text{pitch} + f \times \text{least count}$, where n = main scale reading & f = caps scale reading

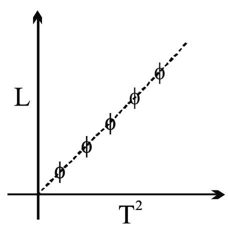
Zero Error : In a perfect instrument the zero of the head scale coincides with the line of graduation along the screw axis with no zero-error, otherwise the instrument is said to have zero-error which is equal to the cap reading with the gap closed. This error is positive when zero line or reference line of the cap lies **below** the line of graduation and versa. The corresponding corrections will be just opposite.

(ii) **Measurement of g using a simple pendulum**

A small spherical bob is attached to a cotton thread and the combination is suspended from a point A. The length of the thread (L) is read off on a meter scale. A correction is added to L to include the finite size of the bob and the hook. The corrected value of L is used for further calculation. The bob is displaced slightly to one side and is allowed to oscillate, and the total time taken for 50 complete oscillations is noted on a stop-watch.

The time period (T) of a single oscillation is now calculated by division.

Observations are now taken by using different lengths for the cotton thread (L) and pairs of values of L and T are taken. A plot of L v/s T^2, on a graph, is linear. g is given by $g = 4\pi^2 \frac{L}{T^2}$



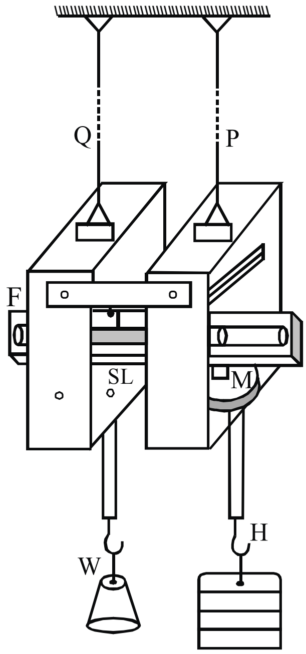
The major errors in this experiment are

(a) **Systematic :** Error due to finite amplitude of the pendulum (as the motion is not exactly SHM). This may be corrected for by using the correct numerical estimate for the time period. However the practice is to ensure that the amplitude is small.

(b) **Statistical :** Errors arising from measurement of length and time. $\frac{\delta g}{g} = \frac{\delta L}{L} + 2\left(\frac{\delta T}{T}\right)$

The contributions to δL, δT are both statistical and systematic. These are reduced by the process of averaging. The systematic error in L can be reduced by plotting several values of L vs T^2 and fitting to a straight line. The slope of this fit gives the correct value of L/T^2

(iii) **Determination of Young's Modulus by Searle's Method**



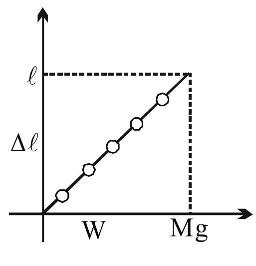
The experimental set up consists of two identical wires P and Q of uniform cross section suspended from a fixed rigid support. The free ends of these parallel wires are connected to a frame F as shown in the figure. The length of the wire Q remains fixed while the load L attached to the wire P through the frame F is varied in equal steps so as to produce extension along .the length. The extension thus produced is measured with the help of spirit level SL and micrometer screw M attached to the F frame on the side of the experimental wire. On placing the slotted weights on the hanger H upto a permissible value (half of the breaking force) the wire gets extended by small amount and the spirit level gets disturbed from horizontal setting. This increase in length is measured by turning the micrometer screw M upwards so as to restore the balance of the spirit level. If n be the number of turns of the micrometer screw and f be the difference in the cap reading, the increase in length M is obtained by $\Delta l = n \times \text{pitch} + f \times \text{least count}$

In some situations, the change in length is obtained by vernier arrangement instead of the screw gauge.

The load on the hanger is reduced in the same steps and spirit level is restored to horizontal position. The mean of these two observations gives the true increase in length of the wire corresponding to the given value of load. This is to eliminate the effect of hysteresis.

From the data obtained, a graph showing extension (Δl) against the load (W) is plotted which is obtained as a straight line passing through the origin.

The slope of the line gives $\tan\theta = \frac{l}{W} = \frac{l}{Mg}$



Now, stress $= \frac{Mg}{\pi r^2}$ and strain $= \frac{l}{L}$

$$Y = \text{Stress/ strain} = \frac{MgL}{\pi r^2 l} = \frac{L}{\pi r^2 \tan\theta}$$

With known values of initial length L, radius r of the experimental wire and $\tan\theta$, Young's modulus Y can be calculated.

(iv) Specific Heat of a liquid using a calorimeter:

The principle is to take a known quantity of liquid in an insulated calorimeter and heat it by passing a known current (i) through a heating coil immersed within the liquid for a known length of time (t).

The mass of the calorimeter (m_1) and, the combined mass of the calorimeter and the liquid (m_2) are measured. The potential drop across the heating coil is V and the maximum temperature of the liquid is measured to θ_2.

The specific heat of the liquid (S_l) is found by using the relation

$$(m_2 - m_1)S_l(\theta_2 - \theta_0) + m_1S_c(\theta_2 - \theta_0) = i.\ V.\ t$$

or, $$(m_2 - m_1)S_l + m_1S_c = i.\ V.\ t/(\theta_2 - \theta_0) \qquad ..... (1)$$

Here, θ_0 is the room temperature, while S_c is the specific heat of the material of the calorimeter and the stirrer. If S_c is known, then S_l can be determined.

On the other hand, if S_c is unknown: one can either repeat the experiment with water or a different mass of the liquid and use the two equations to eliminate m_1S_c.

The sources of error in this experiment are errors due to improper connection of the heating coil, radiation, apart from statistical errors in measurement.

Error analysis :

After correcting for systematic errors, equation (1) is used to estimate the remaining errors.

(v) Focal length of a concave mirror and a convex lens using the u-v method.

In this method one uses an optical bench and the convex lens (or the concave mirror) is placed on the holder.

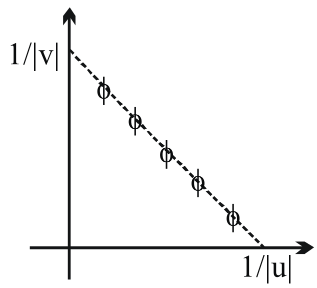
The position of the lens is noted by reading the scale at the bottom of the holder. A bright object (a filament lamp or some similar object) is placed at a fixed distance (u) in front of the lens (mirror).

The position of the image (v) is determined by moving a white screen behind the lens until a sharp image is obtained (for real images).

For the concave mirror, the position of the image is determined by placing a sharp object (a pin) on the optical bench such that the parallax between the object pin and the image is nil.

A plot of |u| versus |v| gives a rectangular hyperbola. A plot of $\frac{1}{|v|}$ vs $\frac{1}{|u|}$ gives a straight line.

The intercepts are equal to $\frac{1}{|f|}$, where f is the focal length.



Error : The systematic error in this experiment is mostly due to improper position of the object on the holder. This error maybe eliminated by reversing the holder (rotating the holder by 180° about the vertical) and then taking the readings again. Averages are then taken.

The equation for random errors gives: $\frac{\delta f}{f^2} = \frac{\delta u}{u^2} + \frac{\delta v}{v^2}$

The errors δu, δv correspond to the error in the measurement of u and v. Actually, we know the errors in the object position, lens position & image position. So, the errors in u & v are too be estimated as described before.

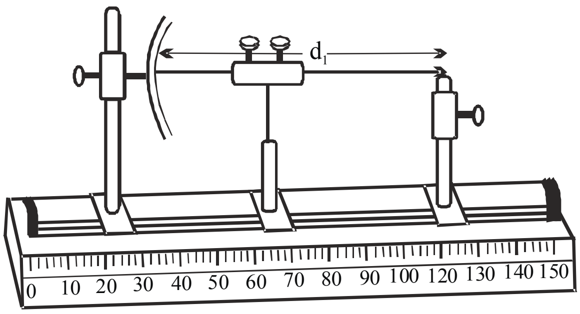
Index Error or Bench Error and its correction:

In an experiment using an optical bench we are required to measure the object and image distances from the pole or vertex on the mirror. The distance between the tip of the needles and the pole of the mirror is the actual distance. But we practically measure distances between the indices with the help of the scale engraved on the bench. These distances are called the observed distances. The actual distances may not be equal to the observed distances and due to this reason an error creeps in the measurement of the distances. This error is called the index or the bench error. This error is estimated with the help of a needle of known length placed horizontally between the tip of the needle and the pole.

Index Error = Observed distance – actual distance and

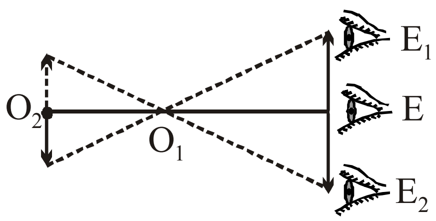
Index Correction = Actual – observed distance

Note: Index correction whether positive or negative, is always added algebraically to the observed distance to get the corrected distance.



Parallax

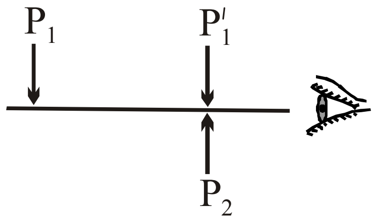
When two objects O_1 and O_2 are placed in such a way that both of them lie in the same line of sight as shown in figure, then the object nearer to the eye covers the object farther from it. Their images on the retina are superimposed and therefore, it is impossible to decide which is the nearer object. To identify this fact, the observer displaces his eye to a position E_1 or E_2 until he is able to see two distinct objects.



The more distant object O_2 apparently moves in the direction opposite to the displacement of the observer's eye with respect to the nearer object O_1. This relative shift in the position of two objects due to the shift in the position of the observer's eye is called parallax.

Parallax between the two objects disappear if they are at the same position.

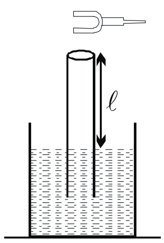
The figure shows the tips of two pins P_1 and P_2 kept in the upright positions. The parallax between P_1 and P_2 is removed by shifting the position of observer's eye sideways. As the farther pin P_1 is displaced towards the pin P_2 the relative shift (parallax) between their positions decreases as the position of eye is displaced sideways. The relative shift vanishes when the pin P_1 occupies the position P'_1, that is , when the tips of the two are just coincident. At this position there is no parallax between the tips of the two pins.



(vi) Speed of sound using resonance column

A tuning fork of known frequency (f) is held at the mouth of a long tube, which is dipped into water as shown in the figure. The length (l_1) of the air column in the tube is adjusted until it resonates with the tuning fork. The air temperature and humidity are noted. The length of the tube is adjusted again until a second resonance length (l_2) is found (provided the tube is long)

Then, $l_2 - l_1 = \lambda / 2$, provided l_1, l_2 are resonance lengths for adjacent resonances.



$\therefore\ \lambda = 2(l_2 - l_1)$, is the wavelength of sound.

Since the frequency f, is known; the velocity of sound in air at the temperature (θ) and humidity (h) is given by $C = f\lambda = 2(l_2 - l_1)f$

It is also possible to use a single measurement of the resonant length directly, but, then it has to be corrected *for* the "end effect":

$\lambda(\text{fundamental}) = 4(l_1 + 0.3d)$, where d = diameter

Errors :

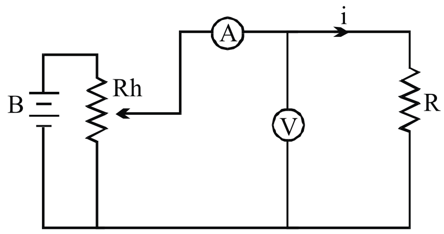
The major systematic errors introduced are due to end effects in (end correction) and also due to excessive humidity.

Random errors are given by $\dfrac{\delta C}{C} = \dfrac{\delta(l_2 - l_1)}{l_2 - l_1} = \dfrac{\delta l_2 + \delta l_1}{l_2 - l_1}$

(vii) Verification of Ohm's law using voltmeter and ammeter

A voltmeter (V) and an ammeter (A) are connected in a circuit along with a resistance R as shown in the figure, along with a battery B and a rheostat, Rh

Simultaneous readings of the current i and the potential drop V are taken by changing the resistance in the rheostat (Rh). A graph of *V* vs *i* is plotted and it is found to be linear (within errors). The magnitude of R is determined by either



(a) taking the ratio $\frac{V}{i}$ and then (b) fitting to a straight line: V = iR, and determining the slope R.

Errors :

Systematic errors in this experiment arise from the current flowing through V (finite resistance of the voltmeter), the Joule heating effect in the circuit and the resistance of the connecting wires/ connections of the resistance. The effect of Joule heating may be minimized by switching on the circuit for a short while only, while the effect of finite resistance of the voltmeter can be overcome by using a high resistance instrument or a potentiometer. The lengths of connecting wires should be minimized as much as possible.

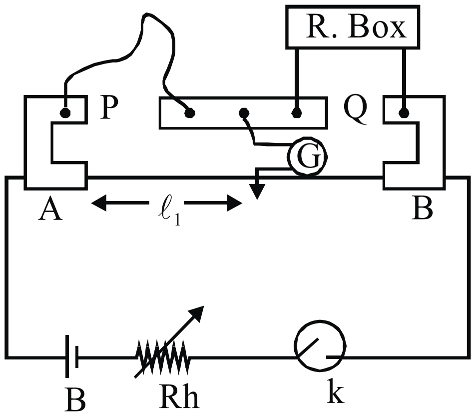
Error analysis :

The error in computing the ratio $R = \frac{V}{i}$ is given by $\left|\frac{\delta R}{R}\right| = \left|\frac{\delta V}{V}\right| + \left|\frac{\delta i}{i}\right|$

where δV and δi are of the order of the least counts of the instruments used.

(viii) Specific resistance of the material of a wire using a meter bridge :

A known length (*l*) of a wire is connected in one of the gaps (P) of a metre bridge, while a Resistance Box is inserted into the other gap (Q). The circuit is completed by using a battery (B), a Rheostat (Rh), a Key (K) and a galvanometer (G).The balance length (*l*) is found by closing key K and momentarily connecting the galvanometer until it gives zero deflection (null point). Then, $\frac{P}{Q} = \frac{l}{100 - l}$ ....(1)



using the expression for the meter bridge at balance. Here P represents the resistance of the wire while Q represents the resistance in the resistance box. The key K is open when the circuit is not in use.

The resistance of the wire, $P = \rho\dfrac{L}{\pi r^2} \Rightarrow \rho = \dfrac{\pi r^2}{L}P$ ....(2)

where r is the radius of wire and L is the length of the wire, r is measured using a screw gauge while L is measured with a scale.

Errors :

The major systematic errors in this experiment are due to the heating effect, end corrections introduced due to shift of the zero of the scale at A and B, and stray resistances in P and Q, and errors due to non-uniformity of the meter bridge wire.

Error analysis :

End corrections can be estimated by including known resistances P_1 and Q_1 in the two ends and finding the null point:

$$\frac{P_1}{Q_1} = \frac{l_1 + \alpha}{100 - l_1 + \beta} \quad \text{..... (2),}$$

where α and β are the end corrections.

When the resistance Q_1 is placed in the left gap and P_1 in the right gap,

$$\frac{Q_1}{P_1} = \frac{l_2 + \alpha}{100 - l_2 + \beta} \quad \text{..... (3)}$$

which give two linear equation for finding α and β.

In order that α and β be measured accurately, P_1 and Q_1 should be as different from each other as possible. For the actual balance point, $\dfrac{P}{Q} = \dfrac{l + \alpha}{100 - l + \beta} = \dfrac{l_1'}{l_2'}$,

Errors due to non-uniformity of the meter bridge wire can be minimized by interchanging the resistances in the gaps P and Q. $\therefore \dfrac{\delta P}{P} = \left|\dfrac{\delta l_1'}{l_1'}\right| + \left|\dfrac{\delta l_2'}{l_2'}\right|$

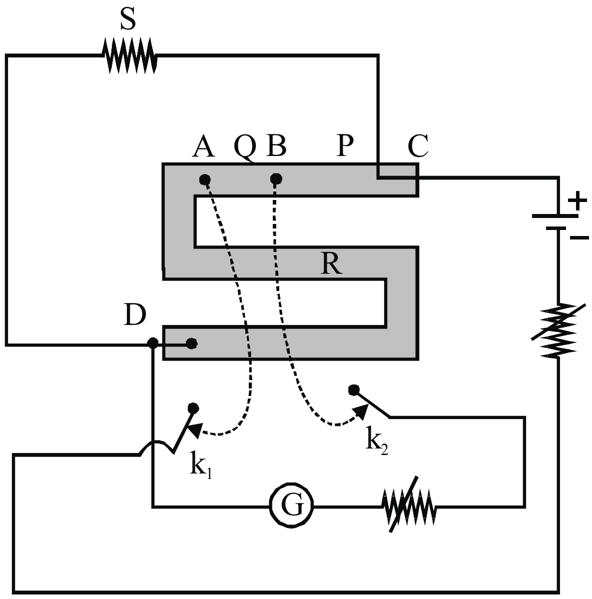
where, $\delta l'_1$ and $\delta l'_2$ are of the order of the least count of the scale.

The error is, therefore, minimum if $l'_1 = l'_2$ i.e. when the balance point is in the middle of the bridge.

The error in ρ is $\frac{\delta\rho}{\rho} = \frac{2\delta r}{r} + \frac{\delta L}{L} + \frac{\delta P}{P}$

(ix) Measurement of unknown resistance using a P.O. Box

A P.O. Box can also be used to measure an unknown resistance. It is a Wheatstone Bridge with three arms P, Q and R; while the fourth arm(s) is the unknown resistance. P and Q are known as the ratio arms while R is known at the rheostat arm. At balance, the unknown resistance



$$S = \left(\frac{P}{Q}\right)R \qquad .....(1)$$

The ratio arms are first adjusted so that they carry 100 Ω each. The resistance in the rheostat arm is now adjusted so that the galvanometer deflection is in one direction, if $R = R_0$ (Ohm) and in the opposite direction when $R = R_0 + 1$ (ohm).

This implies that the unknown resistance, S lies between R_0 and $R_0 + 1$ (ohm). Now, the resistance in P and Q are made 100 Ω and 1000 Ω respectively, and the process is repeated.

Equation (1) is used to compute S.

The ratio P/Q is progressively made 1:10, and then 1 :100. The resistance S can be accurately measured.

Errors :

The major sources of error are the connecting wires, unclear resistance plugs, change in resistance due to Joule heating, and the insensitivity of the Wheatstone bridge.

These may be removed by using thick connecting wires, clean plugs, keeping the circuit on for very brief periods (to avoid Joule heating) and calculating the sensitivity.

In order that the sensitivity is maximum, the resistance in the arm P is close to the value of the resistance S.

METER BRIDGE

Wheatstone Bridge :

Wheatstone bridge is a special electric network in which four resistors P, Q, R and X are connected to form the four arms of a quadrilateral ABCD. A cell with key K_1 is connected across the diagonal AC and a galvanometer with key K_2 across another diagonal BD. The arrangement may be used to measure resistance of a conductor accurately.

The resistances P and Q are kept in a fixed ratio and hence they are said to form the ratio arms of the bridge. Unknown resistance is placed for resistance X and R is a resistance box to provide variable known resistance in steps.

After closing keys K_1 and K_2 resistance in resistance box R may be adjusted to obtain null deflection in galvanometer. In this situation bridge is said to be balanced. When bridge is balanced, B and D must be at same potential.

$V_B = V_D$

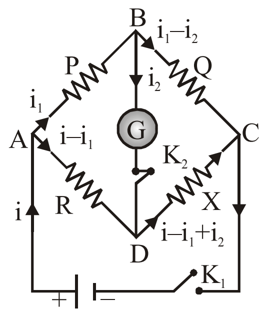
no current flows through the galvanometer i.e., $i_2 = 0$

$\therefore \quad V_A - V_B = V_A - V_D$ and $V_B - V_C = V_D - V_C$

$\Rightarrow \quad Pi_1 = R(i - i_1)$ ....(i) and $Q(i_1 - i_2) = X(i - i_1 + i_2)$ ....(ii)

$Qi_1 = X(i - i_1)$ .... (iii)

Dividing (i) and (iii), we get $\frac{P}{Q} = \frac{R}{X}$



This, is the condition of balanced bridge. [Wheatstone bridge]

In balancing condition of the bridge, unknown resistance can be calculated.

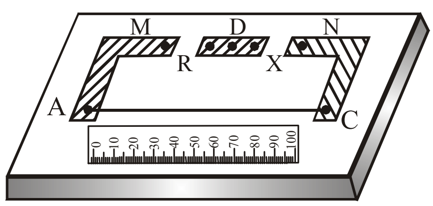
$$X = R\frac{Q}{P}$$

Two practical versions of Wheatstone bridge are

(a) Post office box, and (b) Meter bridge or slide wire bridge.

Meter Bridge:

A meter bridge consists of a one meter long wire AC, made of a homogeneous material constantan or eureka alloy and having a uniform cross-section. The wire is stretched on a wooden board. A meter scale is fixed on the board parallel to the wire. The ends A and C of the wire are fixed to two thick copper strips M and N respectively. Another strip D is fixed between strips M and N to form two gaps for introducing resistances R and X. Connecting terminals are attached at the ends of the copper strips and also in the middle of strip D for making connections.

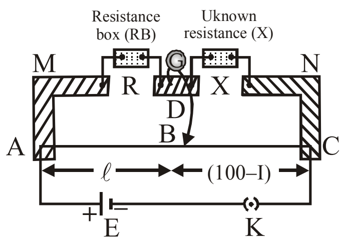


EXPERIMENT

Object :- To find resistance of a given wire using a metre bridge and hence determine the specific resistance of its material.

Apparatus required : A resistance box, a wire about 1 metre long (of the material whose specific resistance is to be determined), a metre bridge, a jockey, one- way key, a galvanometer, a battery eliminator or a cell, thick connecting wires, sand paper, screw gauge etc.

Required formula : Unknown resistance $X = R\left(\frac{100-\ell}{\ell}\right)$ and specific resistance of the material of the given wire, $\rho = \frac{XA}{L} = \frac{X(\pi r^2)}{L}$, where r and L are the radius and length of the given wire respectively.



Procedure :

1. Arrange the meter bridge and the various component as shown in figure and make tight connections. Putting RB in right gap and X in left gap
2. Take out the plug from RB to introduce a suitable resistance say, R = 2Ω and close the key K.
3. Now, touch the jockey on meter-bridge wire at different places to obtain such a position, where there is no deflection in the galvanometer. At this condition
   AB = ℓ and BC = (100 – ℓ)
   Putting RB in left gap and X in right gap
4. Repeat step 2 and 3. But in this balancing condition BC = ℓ and AB = (100 – ℓ)
5. Now disconnect the unknown resistance wire from the circuit. Straighten it by stretching and remove any kinks and measure its length with the help of a metre scale.
6. Measure the diameter of the wire with the help of a screw gauge.

Precautions :

1. The connections should be neat, clean and tight.
2. All the plugs in the resistance box should be tight
3. While moving the jockey to locate the balance point, the jockey should be lifted again and again and should not be pressed and slided on the wire throughout.
4. The plug in key K should be inserted only when the observations are to be taken.
5. The balance point should always be obtained near the midpoint or in between from 30 cm to 70 cm.
6. Diameter of wire should be measured in two mutually perpendicular direction at one place.

Source and of error :

1. The plugs may not be clean.
2. The meter bridge wire may not have uniform cross-section.
3. Connections may loose.
4. The screw gauge may have faulty calibration or backlash error.

OHM'S LAW

OHM'S LAW :

According to this law the ratio of the potential difference across any conductor to the electric current flowing through it is constant, under constant physical conditions i.e. temperature, pressure etc. If V is the potential difference between the two points along a conductor and I is current flowing through it, then $\frac{V}{I}$ = constant. This constant is known as resistance of the conductor represented by R.

So, V = IR

Resistance :

Obstruction in the flow of charge through a conductor is called a resistance. Its S.I. unit is Ohm (Ω).

Conductance :

The inverse of resistance is known as conductance. Its S.I. unit is $(\text{ohm})^{-1}$ or mho or siemen.

Specific resistance or resistivity :

For conductors of given material at given temperature, the resistance is directly proportional to the length ℓ and inversely proportional to the area of cross-section A, i.e.,

$$R \propto \frac{\ell}{A} \Rightarrow R = \frac{\rho\ell}{A}$$

where ρ is a constant which depends upon the nature of the material and is called resistivity or specific resistance of the conductor. For unit length and unit area of cross-section, $\rho = R$; so specific resistance is the resistance of a conductor of unit length and of unit area of cross-section. Its S.I. unit is ohm-metre.

Temperature dependenc of resistivity :

When temperature of a conductor increases, ρ increases as; $\rho_\theta = \rho_0 (1 + \alpha\theta)$. Resistance of metals increase with rise in temperature. $R_\theta = R_0 (1 + \alpha\theta)$, where α is coefficient of resistance given as

$$\alpha = \frac{R_\theta - R_0}{R_0.\theta} (°C)^{-1}$$

Electrical conductivity :

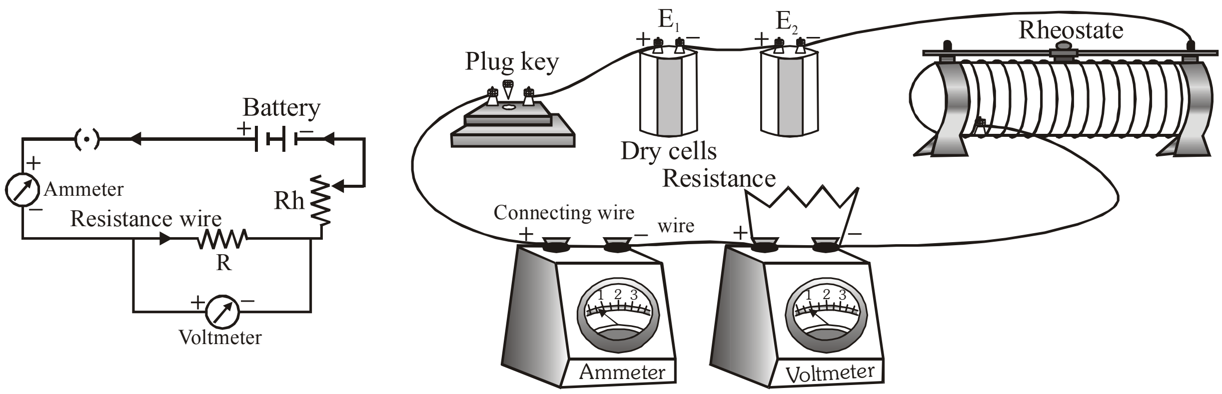
Electrical conductivity is the inverse of term resistivity and is denoted by sigma (σ) given, as,

$$\sigma = \frac{1}{\rho} = \frac{\ell}{RA} \text{ (S.I. unit of } \sigma \text{ is ohm}^{-1}\text{m}^{-1})$$

EXPERIMENT

Object :- To determine the resistance of a given wire by plotting a graph of potential difference versus current.

Apparatus required :- A given resistance wire in the form of a coil, a battery eliminator or an accumulator or two dry cells, a dc voltmeter, a dc ammeter, a rheostat, one plug key, thick connecting wire, sand paper etc.



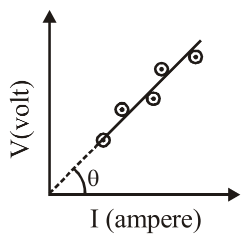
Circuit Diagram

Procedure:

1. Draw the circuit diagram as shown in figure.
2. Note the range, the least count, and the zero error of voltmeter as well as that of the ammeter.
3. Insert the plug in key K. Slide the rheostate contact to the extreme right figure. So that the current passing through the resistance wire is minimum.
4. Adjust the rheostate and record the readings of the ammeter and the voltmeter. Then shift the rheostate contact to increase the current and note readings again. Take similarly ten observations.
5. Cut the resistance wire at the ends just coming out of voltmeter and measure its length 'ℓ', using metre scale.

Graph :

Using the readings of voltmeter (V) and ammeter (I) draw a graph as straight line best fitting all the points.



Calculation :

$$\text{Slope of V–I curve} = \frac{\Delta V}{\Delta I} = \tan\theta = R$$

Precautions :

1. Connections should be neat, clean and tight.
2. Connecting wires should be of thick copper wires.
3. Voltmeter and ammeter should be of proper range.
4. The key/plug should be inserted only while taking observations, otherwise current gives unnecessary heating of wires.
5. The unknown resistance should not be too low (than internal resistance of battery)

Sources of error :

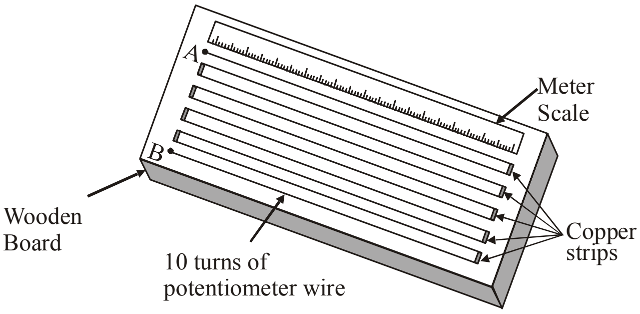
1. Connections may be loose.
2. Rheostate may have very high resistance.
3. The unknown resistance may be too low.
4. Thick connecting wires may not be available.

POTENTIOMETER

Potentiometer :

1. It is a device used to measure potential difference between two point in an electric circuit or emf of a cell with greater accuracy.
2. It behaves like an ideal voltmeter means its effective resistance is infinity.
3. It uses the concept of zero deflection during measurement.

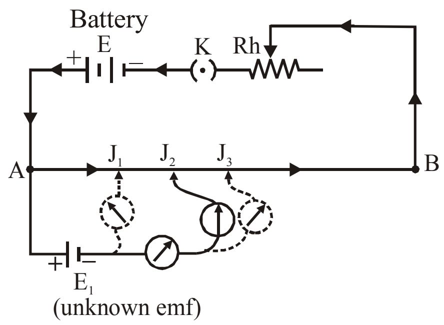
Construction :-



A thin, long, straight and uniform wire AB of constantan or manganin, which has a low temperature coefficient of resistance and high resistivity, is stretched on a wooden board along a meter-scale. The longer wire (taken long to increase accuracy) is arranged in the form of parallel wires and its ends are connected by thick strips of copper, so that the current flows through the wires in series.

Principle :

When a steady current flows through the potentiometer wire from the end A to B, as shown in figure, by a battery E then an electric potential falls uniformly along the whole length of the wire. This fall in potential per unit length of the wire, is known s "potential gradient".



Due to the constant current through potentiometer wire potential difference between any two points on the wire is directly proportional to the distance between the points, means

$V \propto \ell$

$\Rightarrow \quad V = x\ell \quad$ or $\quad \dfrac{V}{\ell} = x$ = potential gradient

By comparing the unknown emf, say as E_1 in the figure, with the help of a galvanometer to the uniformly distributed potential over the wire, we can find the value of unknown. So, now suppose the jockey is made to touch a point J_1 on the wire such that the potential difference between A and J_1 is lower than the emf of E_1, then a resultant current flows through the secondary circuit or galvanometer and the needle of the galvanometer deflects in one direction.

On the other hand, if the jockey is made to touch a point J_2 on the wire such that the potential difference between A and J_2 is higher than the emf of the cell E_1, then a resultant current flows in opposite direction than previous one in the galvanometer and its needle deflects in the opposite side. It is evident that in between J_1 and J_2, there will be a point J such that when the jockey is made to touch on J, there will be no deflection in the galvanometer. This point J is called **balancing/null point** and the distance AJ is called **balancing length.** At this situation.

p.d. between A and J = emf of the cell

$\Rightarrow \quad x\,\ell = E_1 \quad \Rightarrow \quad E_1 = x\ell$

where x - potential gradient

ℓ - balancing length

E_1 - unknown emf

Sensitivity of Potentiometer :

If on displacing the jockey slightly from the null point position, the galvanometer shows a large deflection, then the potentiometer is said to be sensitive. The sensitivity of the potentiometer depends upon the potential **gradient as :** sensitivity of potentiometer $\propto \dfrac{1}{\text{potential gradient}}$

The potential gradient can be reduced by employing a long wire in the potentiometer.

EXPERIMENT

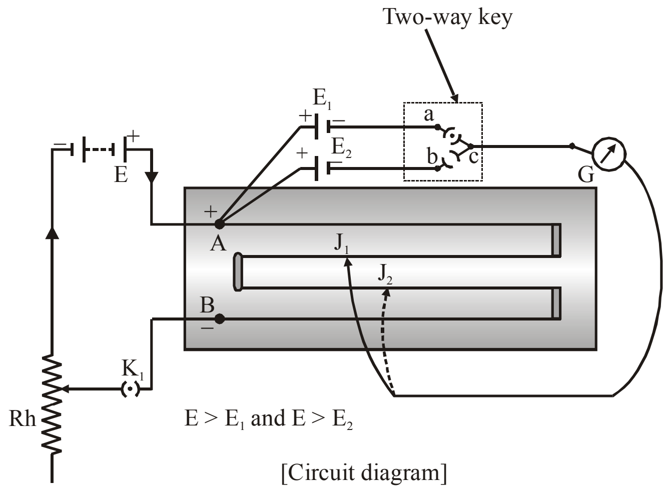
Object :- To compare the emf of two given primary cells (Daniel and Lechlanche Cell) using a potentiometer.

Apparatus required : A battery eliminator, a low resistance box about 20Ω, a one way key, two primary cells (Daniel and Lechlanche), one two way key, a resistance box plug type, a galvanometer, a potentiometer with a sliding jockey, connecting wires etc.

Formula required : $\dfrac{E_1}{E_2} = \dfrac{\ell_1}{\ell_2}$

where E_1 and E_2 are the emf's of the given primary cells and ℓ_1 and ℓ_2 are their respective balancing lengths on potentiometer wire.

Circuit diagram :



[Circuit diagram]

Procedure :

1. Arrange the circuit as shown in figure and plug key K_1.
2. In this circuit, by inserting the plug in the gap ac, cell E_1 comes in the secondary circuit. Introduce minimum resistance by Rh (rheostate) and then press the jockey at one end of the wire and note the direction of deflection in the galvanometer. Now repeat the same process with the jockey pressed near the other end of the wire and note the direction of deflection. The connections are correct if two deflections are in opposite directions.
3. If deflections are obtained in same direction, check connections and assure that $E > E_1$ and $E > E_2$.
4. After this, touch the jockey at different places on the wire and obtain a balance point, where on pressing the jockey, there is no deflection in the galvanometer note the length AJ_1 as ℓ_1 .
5. Introduce E_2 in the S circuit by transferring the plug ac to bc. Obtain the balancing point J_2 and note the length AJ_2 as ℓ_2.
6. Repeat the experiment by shifting the contact point of rheostate.

Precautions :

1. The plugs should be introduced in the keys only when the observations are to be taken.
2. The positive poles of the battery and cells E_1 and E_2 should all be connected to the terminal at zero of the wires.
3. The emf of the battery should be greater than the emfs of either of the two cells.
4. The jockey should not be rubbed along the wire. It should touch the wire gently.
5. The current should not be passed for a long time so as to avoid any heating of the wires resulting into change of resistance.
6. The balancing poing should always be obtained at large distance and if possible it should be obtained at the last wire.

Source of error :

1. The battery (E) may not be fully charged.
2. By rubbing the jockey on the wire, it may not have uniform cross-section throughout its length.
3. The resistance of copper strips may not be zero.
4. Due to the current passed through the wire for a long time, its resistance may change.

EXPERIMENT

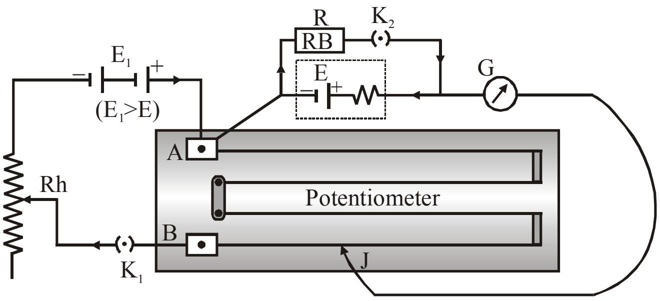
Object : To determine the internal resistance of a given primary cell by using a potentiometer.

Apparatus required : Battery eliminator or cells in series, connecting wires, a rheostate, a galvanometer, a lechlanche cell, a resistance box, two one-way keys, a potentiometer with a sliding jockey etc.

Formula required : Internal resistance of a (primary) cell is $r = R\left(\frac{\ell_1}{\ell_2} - 1\right)$

where R–resistance used across the cell, ℓ_1 and ℓ_2 are the balancing lengths for the cell when it is in open and closed circuit respectively.

Circuit diagram :



[Circuit diagram]

Procedure :

1. Make the circuit as shown and ensure that the connections are tight and clean.
2. Keeping the key K_2 open, insert the plug in key K_1 and put the jockey near the end A and press it. Note the direction of deflection in galvanometer.
   Again note the direction of deflection by moving the jockey to the other end B and pressing.
   The deflection in these cases must be in opposite directions. If it is not so, then check the connections and adjust the rheostate so that the above condition is achieved.
3. Keeping K_2 open and K_1 close, obtain the balancing length for the emf of cell and note it as ℓ_1.
4. Introduce some resistance (R) from the resistance box and close K_2 now and then obtain balancing length again and record it as ℓ_2.
5. Repeat the experiment for the different values of R and obtain different readings of ℓ_2.

Precautions :

1. Reading should be taken quickly as possible.
2. The cell should not be disturbed during the course of experiment.
3. The positive terminals of battery and cell should be connected at one point A.
4. Emf of the battery should be greater than the emf of lechanche cells.
5. All connections should be tight, neat and clean
6. The jockey should not be rubbed along the wire. It should touch the wire gently.

Source of error :

1. The battery (E) may not be fully charged.
2. By rubbing the jockey on the wire, it may not have uniform cross-section throughout its length.
3. The resistance of copper strips may not be zero.
4. Due to the current passed through the wire for a long time, its resistance may change.

GALVANOMETER

Galvanometer :

- It is a device which is used to detect the presence of current or to measure weak current in the circuit.
- It is based on the principle that a current carrying coil placed in a uniform magnetic field experiences a torque.
- Basically, galvanometers are of two types :
  (i) Moving coil type
  (ii) Moving Magnet type (Tangent Galvanometer)

Principle of a moving coil galvanometer

When a current I is flowing through a coil in a uniform magnetic field, the coil experiences first deflecting torque τ =NAIB and then restoring torque $\tau = C\theta$. Because both the torque oppose each other, therefore in equilibrium.

$$\tau_{\text{deflecting}} = \tau_{\text{restoring}}$$

$$NIAB = c\theta \Rightarrow \quad I = \left(\frac{C}{BAN}\right)\theta = k\theta$$

$\Rightarrow$ $I \propto \theta$ or current α deflection

where $k = \dfrac{C}{BAN}$ = Galvanometer's constant

i.e. deflection of the needle in the galvanometer is directly proportional to the current flowing through it.

(i) **Figure of Merit :** Current required to produce a deflection of one division is called figure of merit of galvanometer.

$$F = \frac{I}{\theta} = k$$

(ii) **Current Sensitivity :** Deflection per unit current is called current sensitivity of galvanometer.

$$S_C = \frac{\theta}{I} = \frac{1}{k} = \frac{1}{F} = \text{reciprocal of figure of merit}$$

(iii) **Voltage sensitivity :** Deflection per unit voltage i.e. $S_V = \dfrac{\theta}{V} = \dfrac{\theta}{IR} = \dfrac{S_C}{R}$

Sp. Note :

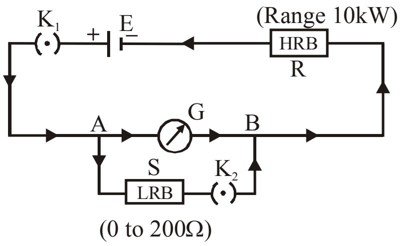
Suspension type moving coil galvanometers are used in advanced laboratories in colleges and universities for very accurate measurements whereas in school laboratories pivoted type (weston) galvanometers are used.

EXPERIMENT

Object : (a) To determine the resistance of a galvanometer by half deflection method and
(b) To find its figure of merit.

Apparatus required : A galvanometer, a battery or accumulator, a low resistance box (LRB), a high resistance box (HRB), two one-way keys, connecting wires etc.

Circuit diagram :

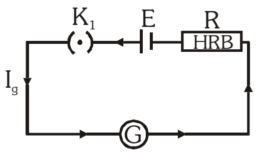


[Circuit diagram]

Theory :

(a) **Resistance of galvanometer by half deflection method :** When a high resistance R is applied in the circuit with K_1 closed and K_2 open, the galvanometer draws a current I_g and shows a deflection θ such that

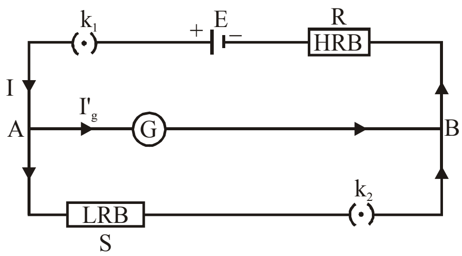
$$I_g = \frac{E}{R+G} \qquad .....(i)$$



where E, is emf of the battery and G is resistance of the galvanometer.

Now K_2 is closed. Adjust the resistance in LRB such that galvanometer deflection becomes equal to $\frac{\theta}{2}$. Now the galvanometer draw the current.

$$I'_g = \frac{IS}{G+S} = \frac{ES}{R(G+S)+GS} \qquad \left(\text{where } I = \frac{E}{R+\frac{GS}{G+S}}\right)$$



Also $\qquad I'_g = \frac{1}{2} I_g$

$\therefore \qquad \frac{ES}{R(G+S)+GS} = \frac{1}{2} \cdot \frac{E}{R+G}$

gives $\qquad G = \frac{RS}{R-S}$

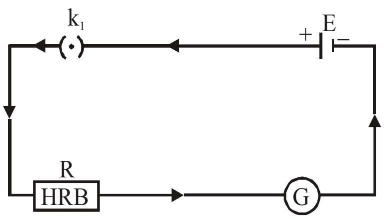
Knowing R and S, G can be calculated.

Also if R > > S, S can be dropped in comparison to R and then $\boxed{G \simeq S}$.

(b) **Figure of merit of galvanometer** is defined as the current required per division of deflection in galvanometer. It is denoted by k. $\qquad$ Figure merit $k = \frac{I}{\theta}$

The circuit diagram for determination of figure of merit (k) of a galvanometer is shown in the figure. When a high resistance R is introduced in the circuit

through HRB, a small current I_g is drawn by it and it shows a deflection θ such that



$$I_g = k\theta = \frac{E}{R+G}$$

$\Rightarrow$ Figure of merit $k = \frac{1}{\theta}\left(\frac{E}{R+G}\right)$ ....(ii)

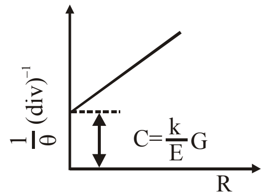
Maximum current measured by galvanometer or full scale deflection current for galvanometer

I_g = Number of division on one side of galvanometer scale × figure of merit

From equation (ii)

$$\frac{1}{\theta} = \frac{k}{E}R + \frac{k}{E}G \quad .....(iii)$$

$\therefore$ Graph between $\frac{1}{\theta}$ and R is as shown.



[Graph between (1/θ) and R]

Procedure :

1. In the circuit, introduce a high resistance R in HRB and then insert the plug in the key K_1. Adjust the value of R to get deflection θ in even number of divisions.
2. Now close the key K_2 also and adjust the shunt resistance S from low resistance box (LRB) to get a deflection exactly half of θ in galvanometer.
3. Repeat experiment for different values of R and θ.

Precautions :

1. All connections in the circuit should be neat, clean and tight.
2. All the plugs in HRB and LRB should be tight.
3. A very high resistance R from HRB should be introduced first and then key K_1 should be closed to avoid any over current damage in galvanometer.
4. The emf of the cell or battery should be constant.
5. The deflection in the galvanometer should be as large as possible and should be even number of divisions.

Sources of error

1. The plugs of HRB and LRB may not be clean.
2. The emf of the battery may not be constant.
3. The galvanometer divisions may not be uniform.

EXERCISE (S)

1. How many significant figures are given in the following quantities ?

(A) 343 g (B) 2.20 (C) 1.103 N (D) 0.4142 s

(E) 0.0145 m (F) 1.0080 V (G) 9.1×10^4 km (H) 1.124×10^{-3} V

ER0001

2. Perform the following operations:

(A) 703 + 7 + 0.66 (B) 2.21×0.3 (C) 12.4×84 (D) 14.28/0.714

ER0002

3. Solve with due regard to significant digits

(i) $\sqrt{6.5-6.32}$ (ii) $\dfrac{2.91\times 0.3842}{0.080}$

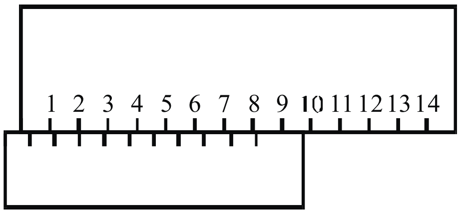
ER0003

4. The main scale of a vernier calipers reads in millimeter and its vernier is divided into 10 divisions which coincide with 9 divisions of the main scale. When the two jaws of the instrument touch each other the seventh division of the vernier scale coincide with a scale division and the zero of the vernier lies to the right of the zero of main scale. Furthermore, when a cylinder is tightly placed along its length between the two jaws, the zero of the vernier scale lies slightly to the left of 3.2 cm; and the fourth vernier division coincides with a scale division. Calculate the measured length of the cylinder.

ER0004

5. The VC shown in the diagram has zero error in it (as you can see). It is given that 9 msd = 10 vsd.

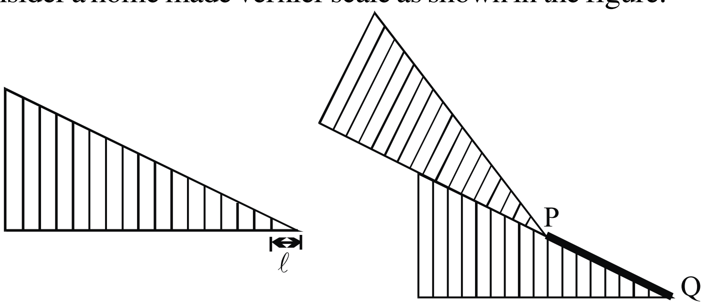
(i) What is the magnitude of the zero error? (1msd = 1 mm)



(ii) The observed reading of the length of a rod measured by this VC comes out to be 5.4 mm. If the vernier had been error free then reading of main scale would be ___ and the coinciding division of vernier scale would be _____.

ER0005

6. Consider a home made vernier scale as shown in the figure.



In this diagram, we are interested in measuring the length of the line PQ. If both the inclines are identical and their angles are equal to θ then what is the least count of the instrument.

ER0065

7. The pitch of a screw gauge is 0.5 mm and there are 50 divisions on the circular scale. In measuring the thickness of a metal plate, there are five divisions on the pitch scale (or main scale) and thirty fourth division coincides with the reference line. Calculate the thickness of the metal plate.

ER0006

8. The pitch of a screw gauge is 1 mm and there are 50 divisions on its cap. When nothing is put in between the studs, 44^{th} division of the circular scale coincides with the reference line zero of the main scale is not visible. When a glass plate is placed between the studs, the main scale reads three divisions and the circular scale reads 26 divisions. Calculate the thickness of the plate.

ER0007

9. In a given optical bench, a needle of length 10 cm is used to estimate bench error. The object needle, image needle & lens holder have their reading as shown.

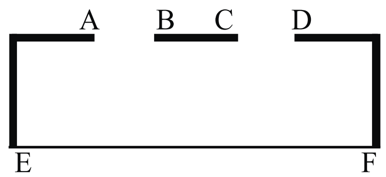
$x_0 = 1.1$ cm $\quad x_I = 21.0$ cm $\quad x_L = 10.9$ cm

Estimate the bench errors which are present in image needle holder and object needle holder. Also find the focal length of the convex lens when.

$x_0 = 0.6$ cm $\quad x_I = 22.5$ cm $\quad x_L = 11.4$ cm

ER0066

10. Make the appropriate connections in the meter bridge set up shown. Resistance box is connected between ___. Unknown resistance is connected between___. Battery is connected between ______.



ER0008

11. A body travels uniformly a distance of (13.8 ± 0.2)m in time (4.0 ± 0.3) sec. Calculate its velocity.

ER0009

12. Consider S = x cos (θ) for x = (2.0 ± 0.2) cm, θ = 53 ± 2 °. Find S.

ER0010

13. Two resistance R_1 and R_2 are connected in (i) series and (ii) parallel. What is the equivalent resistance with limit of possible percentage error in each case of $R_1 = 5.0 \pm 0.2\ \Omega$ and $R_2 = 10.0 \pm 0.1\ \Omega$.

ER0011

14. 5.74 gm of a substance occupies a volume of 1.2 cm^3. Calculate its density with due regard for significant figures.

ER0012

15. The time period of oscillation of a simple pendulum is given by $T = 2\pi\sqrt{l/g}$. The length of the pendulum is measured as $l = 10.0 \pm 0.1$cm and the time period as T = 0.50 ± 0.02 s. Determine percentage error in the value of g.

ER0013

16. In a Searle's experiment, the diameter of the wire as measured by a screw gauge of least count 0.001 cm is 0.050 cm. The length, measured by a scale of least count 0.1 cm, is 110.0 cm. When a weight of 50 N is suspended from the wire, the extension is measured to be 0.125 cm by a micrometer of least count 0.001 cm. Find the maximum error in the measurement of Young's modulus of the material of the wire from these data. **[JEE 2004]**

ER0014

17. The pitch of a screw gauge is 1 mm and there are 100 divisions on the circular scale. While measuring the diameter of a wire, the linear scale reads 1 mm and 47^{th} division on the circular scale coincides with the reference line. The length of the wire is 5.6 cm. Find the curved surface area (in cm^2) of the wire in appropriate number of significant figures. **[JEE 2004]**

ER0015

18. A physical quantity P is related to four observables A, B, C and D as $P = 4\pi^2A^3B^2/(\sqrt{C}\,D)$
The percentage error of the measurement in A, B, C and D are 1%, 3% and 2%, 4% respectively. Determine the percentage error & absolute error in the quantity P. Value of P is calculated 3.763.

ER0067

19. A glass prism of angle $A = 60°$ gives minimum angle of deviation $\theta = 30°$ with the max. error of 1^0 when a beam of parallel light passed through the prism during an experiment. Find the permissible error in the measurement of refractive index μ of the material of the prism.

ER0068

20. In a vernier calipers the main scale and the vernier scale are made up of different materials. When the room temperature increases by $\Delta T°C$, it is found the reading of the instrument remains the same. Earlier it was observed that the front edge of the wooden rod placed for measurement crossed the N^{th} main scale division and $(N + 2)$ msd coincided with the 2^{nd} vsd. Initially, 10 vsd coincided with 9 msd. If coefficient of linear expansion of the main scale is α_1 and that of the vernier scale is α_2 then what is the value of α_1/α_2? (Ignore the expansion of the rod on heating)

ER0069

21. In a vernier callipers, n divisions of its main scale match with (n + 1) divisions on its vernier scale. Each division of the main scale is a units. Using the vernier principle, calculate its least count.

[JEE 2003]
ER0070

22. The period of oscillation of a simple pendulum in an experiment is recorded as 2.63 sec, 2.56 sec, 2.42 sec, 2.71 sec and 2.80 sec respectively. Find the time period, the absolute error in each observation, average absolute error and the percentage error.

ER0016

23. The side of a cube is measured by vernier callipers (10 divisions of a vernier scale coincide with 9 divisions of main scale, where 1 division of main scale is 1 mm). The main scale reads 10 mm and first division of vernier scale coincides with the main scale. Mass of the cube is 2.736 g. Find the density of the cube in appropriate significant figures. **[JEE 2005]**

ER0017

EXERCISE (O)

1. A wire has a mass 0.3 ± 0.003 g, radius 0.5 ± 0.005 mm and length 6 ± 0.06 cm. The maximum percentage error in the measurement of its density is :- **[JEE 2004]**

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

ER0018

2. The edge of a cube is $a = 1.2 \times 10^{-2}$ m. Then its volume will be recorded as : **[JEE 2003]**

(A) $1.7 \times 10^{-6}\ m^3$ (B) $1.70 \times 10^{-6}\ m^3$

(C) $1.70 \times 10^{-7}\ m^3$ (D) $1.78 \times 10^{-6}\ m^3$

ER0019

3. A vernier callipers having 1 main scale division = 0.1 cm is designed to have a least count of 0.02 cm. If n be the number of divisions on vernier scale and m be the length of vernier scale, then :-

(A) n = 10, m = 0.5 cm (B) n = 9, m = 0.4 cm

(C) n = 10, m = 0.8 cm (D) n = 10, m = 0.2 cm

ER0020

4. In the Searle's experiment, after every step of loading , why should we wait for two minutes before taking the readings? (More than one correct.)

(A) So that the wire can have its desired change in length.

(B) So that the wire can attain room temperature.

(C) So that vertical oscillations can get subsided.

(D) So that the wire has no change in its radius.

ER0021

5. In a meter bridge set up, which of the following should be the properties of the one meter long wire?

(A) High resistivity and low temperature coefficient

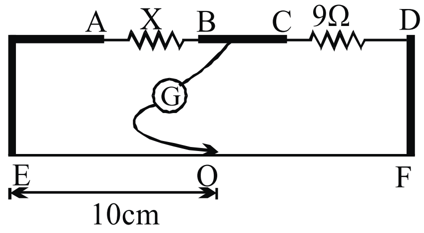
(B) Low resistivity and low temperature coefficient

(C) Low resistivity and high temperature coefficient

(D) High resistivity and high temperature coefficient

ER0022

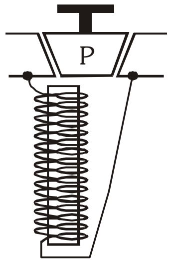
6. Consider the MB shown in the diagram, let the resistance X have temperature coefficient α_1 and the resistance from the RB have the temperature coefficient α_2. Let the reading of the meter scale be 10cm from the LHS. If the temperature of the two resistance increase by small temperature ΔT then what is the shift in the position of the null point? Neglect all the other changes in the bridge due to temperature rise.

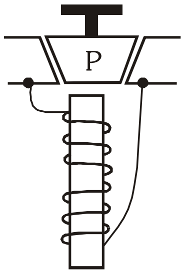


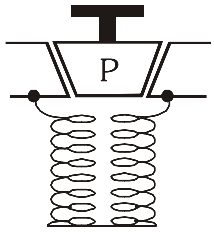
(A) $9(\alpha_1 - \alpha_2)\Delta T$ (B) $9(\alpha_1 + \alpha_2)\Delta T$ (C) $\frac{1}{9}(\alpha_1 + \alpha_2)\Delta T$ (D) $\frac{1}{9}(\alpha_1 - \alpha_2)\Delta T$

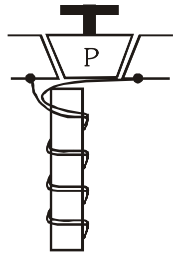
ER0023

7. Identify which of the following diagrams represent the internal construction of the coils wound in a resistance box or PO box?

(A) 

(B) 

(C) 

(D) 

ER0024

8. In a meter bridge experiment, we try to obtain the null point at the middle. This
(A) reduces systematic error as well as random error.
(B) reduces systematic error but not the random error.
(C) reduces random error but not the systematic error
(D) reduces neither systematic error nor the random error

ER0025

9. An approximate value of number of seconds in an year is $\pi \times 10^7$. Determine the % error in this value
(A) 0.5% (B) 8% (C) 4% (D) 15%

ER0071

10. In a Searle's experiment for determination of Young's Modulus, when a load of 50 kg is added to a 3 meter long wire micrometer screw having pitch 1 mm needs to be given a quarter turn in order to restore the horizontal position of spirit level. Young's modulus of the wire if its cross sectional area is 10^{-5} m^2 is
(A) 6×10^{11}N/m^2 (B) 1.5×10^{11} N/m^2 (C) 3×10^{11} N/m^2 (D) None

ER0026

11. On the basis of detail given about two measuring instruments, select the correct statement.

(i) Vernier callipers having main scale division = 0.05 cm and Vernier scale division = $\frac{2.45}{50}$ cm.

(ii) Screw gaugae having pitch 0.5 mm and its circular scale division measures 0.01 mm.
(A) Both the instruments have same least count.
(B) Least count of screw gauge is lesser than that of vernier callipers.
(C) Both the instruments have same least count but screw gauge is more precise.
(D) Both the instruments have different least count and screw gauge is more precise.

ER0027

12. A student obtained following observations in an experiment of meter bridge to find unknown resistance of given wire :

S.No.	**R**	ℓ	**100 –** ℓ	$S=\left(\frac{100-\ell}{\ell}\right)R$
1	2Ω	43	57	2.65
2	3Ω	52	48	2.77
3	4Ω	58	42	2.89
4	5Ω	69	31	2.25

The most accurate value of unknown resistance will be
(A) 2.65 Ω (B) 2.77 Ω (C) 2.89 Ω (D) 2.25 Ω

ER0028

13. In which of the following instruments used in the lab there exists an error of random category known as back lash error

(i) Screw gauge (ii) Spherometer (iii) Searle's apparatus (iv) Vernier callipers

(A) (i) & (ii) only (B) (i), (ii) & (iii) only (C) (i) only (D) all four

ER0029

14. In Searle's apparatus, when experimental wire is loaded and unloaded, the air bubble in spirit level gets shifted.

(A) towards reference wire while loading & towards experimental wire while unloading

(B) towards experimental wire while loading & towards reference wire while unloading

(C) towards experimental wire, both the times, during loading & unloading

(D) towards reference wire, both the times during loading & unloading

ER0030

15. Accuracy and precision are ______(i)_______ and these are respectively linked with ______(ii) & ____(iii)_____ .Fill the blanks above in correct order.

(A) (i) same, (ii) systematic error, (iii) random error

(B) (i) different, (ii) systematic error (iii) random error

(C) (i) same, (ii) random error, (iii) systematic error

(D) (i) different, (ii) random error, (iii) systematic error

ER0031

16. The vernier of a circular scale is divided in to 30 divisions, which coincides with 29 main scale divisions. If each main scale division is $(1/2)^o$, the least count of the instrument is

(A) 0.1' (B) 1' (C) 10' (D) 30'

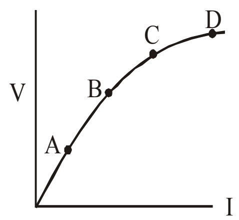
ER0032

17. When the gap is closed without placing any object in the screw gauge whose least count is 0.005 mm, the 5^{th} division on its circular scale coincides with the reference line on main scale, and when a small sphere is placed reading on main scale advances by 4 divisions, whereas circular scale reading advances to five times to the corresponding reading when no object was placed. There are 200 divisions on the circular scale. The radius of the sphere is

(A) 4.10 mm (B) 4.05 mm (C) 2.10 mm (D) 2.05 mm

ER0033

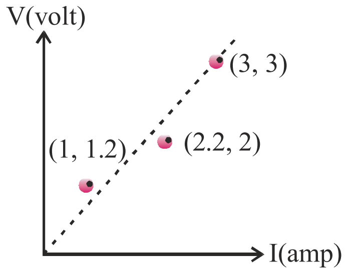
18. Variation of current passing through a conductor as the voltage supplied across its ends as varied is shown in the adjoining diagram. If the resistance (R) is determined at the points A, B, C and D we will find that -



(A) $R_C = R_D$ (B) $R_B > R_A$ (C) $R_C > R_B$ (D) $R_A > R_C$

ER0072

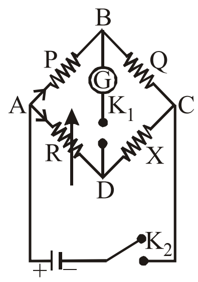
19. In the measurement of resistance of a wire using Ohm's law, the plot between V and I is drawn as shown. The resistance of the wire is -



(A) 0.833 Ω (B) 0.9 Ω (C) 1 Ω (D) None of these

ER0034

20. In Wheatstone bridge experiment as shown in figure –



(A) Key K_1 should be pressed first and then K_2

(B) Key K_2 should be pressed first and then K_1

(C) any key can be pressed in any order

(D) both keys should be pressed simultaneously.

ER0035

21. In a metre bridge experiment null point is obtained at 20 cm from one end of the wire when resistance X is balanced against another resistance Y. If X < Y, then where will be the new position of the null point from the same end, if one decide to balance a resistance of 4X against Y -

(A) 50 cm (B) 80 cm (C) 40 cm (D) 70 cm

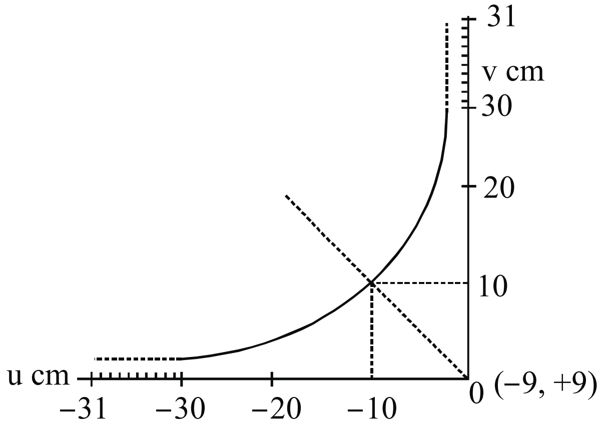
ER0036

22. In a resonance column method, resonance occurs at two successive level of l_1=30.7 cm and l_2 = 63.2 cm using a tuning fork of f = 512 Hz. What is the maximum error in measuring speed of sound using relations $v = f\lambda$ & $\lambda = 2(l_2 - l_1)$ **[JEE 2005]**

(A) 256 cm/sec (B) 92 cm/sec (C) 128 cm/sec (D) 102.4 cm/sec

ER0037

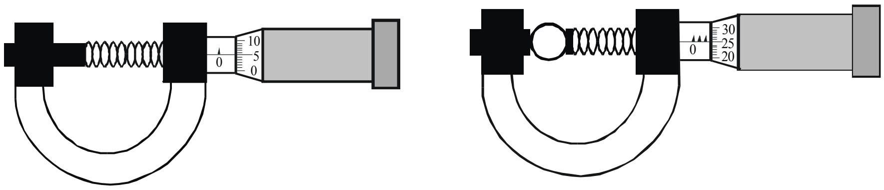
23. Graph of position of image vs position of point object from a convex lens is shown. Then, focal length of the lens is **[JEE 2006]**



(A) 0.50 ± 0.05 cm (B) 0.50 ± 0.10 cm (C) 5.00 ± 0.05 cm (D) 5.00 ± 0.10 cm

ER0038

24. The circular divisions of shown screw gauge are 50. It moves 0.5 mm on main scale in one rotation. The diameter of the ball is **[JEE 2006]**



(A) 2.25 mm (B) 2.20 mm (C) 1.20 mm (D) 1.25 mm

ER0073

25. A student performs an experiment for determination of $g\left(=\frac{4\pi^2 l}{T^2}\right)$ $l \approx 1$m and he commits an error of Δl. For the experiment takes the time of n oscillations with the stop watch of least count ΔT and he commits a human error of 0.1sec. For which of the following data, the measurement of g will be most accurate?

	Δl	ΔT	n	Amplitude of oscillation
(A)	5 mm	0.2 sec	10	5 mm
(B)	5 mm	0.2 sec	20	5 mm
(C)	5 mm	0.1 sec	20	1 mm
(D)	1 mm	0.1 sec	50	1 mm

[JEE 2006]

ER0039

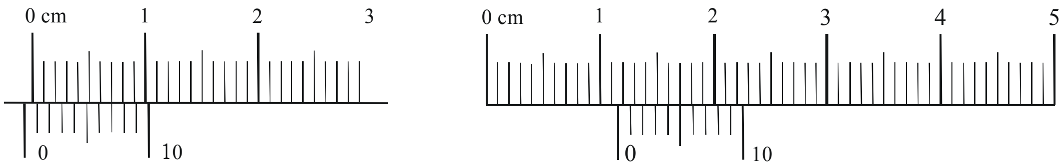
26. In an experiment to determine the focal length (*f*) of a concave mirror by the u-v method, a student places the object pin A on the principal axis at a distance x from the pole P. The student looks at the pin and its inverted image from a distance keeping his/her eye in line with PA. When the student shifts his/her eye towards left, the image appears to the right of the object pin. Then, **[JEE 2007]**

(A) $x < f$ (B) $f < x < 2f$ (C) $x = 2f$ (D) $x > 2f$

ER0040

27. In ordinary Vernier calipers, 10th division of the Vernier scale coincides with 9th division of the main scale. In a specially designed Vernier calipers the Vernier scale is so constructed that 10th division on it coincides with 11th division on the main scale. Each division on the main scale equals to 1 mm. The calipers have a zero error as shown in the figure-I. When the Vernier caliper is used to measure a length, the concerned portion of its scale is shown in figure-II.

Figure-I **Figure-II**



(A) Zero error in the calipers has magnitude 0.7 mm. (B) The length being measured is 1.08 cm.

(C) The length being measured is 1.22 cm. (D) Zero error in the calipers has magnitude 0.3 mm

ER0041

28. A student performs an experiment to determine the Young's modulus of a wire, exactly 2 m long, by Searle's method. In a particular reading, the student measures the extension in the length of the wire to be 0.8 mm with an uncertainty of ± 0.05 mm at a load of exactly 1.0 kg. The student also measures the diameter of the wire to be 0.4 mm with an uncertainty of ± 0.01 mm. Take $g = 9.8$ m/s^2 (exact). The Young's modulus obtained from the reading is **[JEE 2007]**

(A) $(2.0 \pm 0.3) \times 10^{11}$ N/m^2 (B) $(2.0 \pm 0.2) \times 10^{11}$ N/m^2

(C) $(2.0 \pm 0.1) \times 10^{11}$ N/m^2 (D) $(2.0 \pm 0.05) \times 10^{11}$ N/m^2 **ER0042**

EXERCISE-JM

1. An experiment is performed to find the refractive index of glass using a travelling microscope. In this experiment distances are meausred by **[AIEEE - 2008]**

(1) a vernier scale provided on the microscope
(2) a stanard laboratory scale
(3) a meter scale provided on the microscope
(4) a screw gauge provided on the microscope

ER0043

2. Two full turns of the circular scale of gauge cover a diastance of 1 mm on scale. The total number of divisions on circular scale is 50. Further, it is found that screw gauge has a zero error of –0.03 mm. While measuring the diameter of a thin wire a student notes the main scale reading of 3 mm and the number of circular scale division in line, with the main scale as 35. The diameter of the wire is

[AIEEE - 2008]

(1) 3.32 mm (2) 3.73 mm (3) 3.67 mm (4) 3.38 mm

ER0044

3. In an experiment the angles are required to be measured using an instrument 29 divisions of the main scale exactly coincide with the 30 divisions of the vernier scale. If the smallest division of the main scale is half-a-degree (=0.5°), then the least count of the instrument is :- **[AIEEE - 2009]**

(1) One degree (2) Half degree (3) One minute (4) Half minute

ER0045

4. In an optics experiment, with the position of the object fixed, a student varies the position of a convex lens and for each position, the screen is adjusted to get a clear image of the object. A graph between the object distance u and the image distance v, from the lens, is plotted using the same scale for the two axes. A straight line passing through the origin and making an angle of 45° with the x-axis meets the experimental curve at P. The coordinates of P will be :- **[AIEEE - 2009]**

(1) (f, f) (2) $(4f, 4f)$ (3) $(2f, 2f)$ (4) $\left(\frac{f}{2}, \frac{f}{2}\right)$

ER0046

5. The respective number of significant figures for the numbers 23.023, 0.0003 and 2.1×10^{-3} are :- **[AIEEE - 2010]**

(1) 4, 4, 2 (2) 5, 1, 2 (3) 5, 1, 5 (4) 5, 5, 2

ER0047

6. A screw gauge gives the following reading when used to measure the diameter of a wire.
Main scale reading : 0 mm.
Circular scale reading : 52 divisions
Given that 1 mm on main scale corresponds to 100 divisions of the circular scale.
The diameter of wire from the above date is :- **[AIEEE - 2011]**

(1) 0.026 cm (2) 0.005 cm (3) 0.52 cm (4) 0.052 cm

ER0048

7. A spectrometer gives the following reading when used to measure the angle of a prism. Main scale reading : 58.5 degree

Vernier scale reading : 09 divisions

Given that 1 division on main scale corresponds to 0.5 degree. Total divisions on the vernier scale is 30 and match with 29 divisions of the main scale. The angle of the prism from the above data :

[AIEEE - 2012]

(1) 59 degree (2) 58.59 degree (3) 58.77 degree (4) 58.65 degree

ER0049

8. Resistance of a given wire is obtained by measuring the current flowing in it and the voltage difference applied across it. If the percentage errors in the measurement of the current and the voltage difference are 3% each, then error in the value of resistance of the wire is :- **[AIEEE - 2012]**

(1) 3% (2) 6% (3) zero (4) 1%

ER0050

9. The current voltage relation of diode is given by $I = (e^{1000V/T} - 1)$ mA, where the applied voltage V is in volts and the temperature T is in degree Kelvin. If a student makes an error measuring ± 0.01V while measuring the current of 5 mA at 300 K, what will be error in the value of current in mA ?

[JEE-Main 2014]

(1) 0.5 mA (2) 0.05 mA (3) 0.2 mA (4) 0.02 mA

ER0051

10. A student measured the length of a rod and wrote it as 3.50 cm. Which instrument did he use to measure it ? **[JEE-Main 2014]**

(1) A screw gauge having 100 divisions in the circular scale and pitch as 1 mm.

(2) A screw gauge having 50 divisions in the circular scale and pitch as 1 mm.

(3) A meter scale

(4) A vernier calliper where the 10 divisions in vernier scale matches with 9 division in main scale and main scale has 10 divisions in 1 cm.

ER0052

11. The period of oscillation of a simple pendulum is $T = 2\pi\sqrt{\frac{L}{g}}$. Measured value of L is 20.0 cm known to 1 mm accuracy and time for 100 oscillations of the pendulum is found to be 90s using a wrist watch of 1s resolution. The accuracy in the determination of g is : **[JEE-Main 2015]**

(1) 1% (2) 5% (3) 2% (4) 3%

ER0053

12. A screw gauge with a pitch of 0.5 mm and a circular scale with 50 divisions is used to measure the thickness of a thin sheet of Aluminium. Before starting the measurement , it is found that when the two jaws of the screw gauge are brought in contact, the 45th division coincides with the main scale line and that the zero of the main scale is barely visible. What is the thickness of the sheet if the main scale reading is 0.5 mm and the 25th division coincides with the main scale line ? **[JEE-Main 2016]**

(1) 0.50 mm (2) 0.75 mm (3) 0.80 mm (4) 0.70 mm

ER0054

13. A student measures the time period of 100 oscillations of a simple pendulum four times. The data set is 90 s, 91 s, 95 s and 92 s. If the minimum division in the measuring clock is 1 s, then the reported mean time should be :- **[JEE-Main 2016]**

(1) 92 ± 3 s (2) 92 ± 2 s (3) 92 ± 5.0 s (4) 92 ± 1.8 s

ER0055

14. To know the resistance G of a galvanometer by half deflection method, a battery of emf V_E and resistance R is used to deflect the galvanometer by angle θ. If a shunt of resistance S is needed to get half deflection then G, R and S are related by the equation : **[JEE-Mains (Online) 2016]**

(1) $2S(R+G) = RG$ (2) $S(R+G) = RG$ (3) $2G = S$ (4) $2S = G$

ER0056

15. The following observations were taken for determining surface tensiton T of water by capillary method:
Diameter of capilary, $D = 1.25 \times 10^{-2}$ m
rise of water, $h = 1.45 \times 10^{-2}$ m

Using $g = 9.80$ m/s^2 and the simplified relation $T = \frac{rhg}{2} \times 10^3$ N/m, the possible error in surface tension is closest to : **[JEE-Main 2017]**

(1) 2.4% (2) 10% (3) 0.15% (4) 1.5%

ER0057

16. The density of a material in the shape of a cube is determined by measuring three sides of the cube and its mass. If the relative errors in measuring the mass and length are respectively 1.5% and 1%, the maximum error in determining the density is :- **[JEE-Main 2018]**

(1) 3.5 % (2) 4.5 % (3) 6 % (4) 2.5 %

ER0058

SELECTED PROBLEMS FROM JEE-MAINS ONLINE PAPERS

17. The pitch and the number of divisions, on the circular scale, for a given screw gauge are 0.5 mm and 100 respectively. When the screw gauge is fully tightened without any object, the zero of its circular scale lies 3 divisions below the mean line.
The readings of the main scale and the circular scale, for a thin sheet, are 5.5 mm and 48 respectively, the thickness of this sheet is : **[JEE Main-2019_Jan.]**

(1) 5.755 m (2) 5.725 mm (3) 5.740 m (4) 5.950 mm

ER0093

18. The diameter and height of a cylinder are measured by a meter scale to be 12.6 ± 0.1 cm and 34.2 ± 0.1 cm, respectively. What will be the value of its volume in appropriate significant figures ? **[JEE Main-2019_Jan.]**

(1) 4260 ± 80 cm^3 (2) 4300 ± 80 cm^3 (3) 4264.4 ± 81.0 cm^3 (4) 4264 ± 81 cm^3

ER0094

19. The least count of the main scale of a screw gauge is 1 mm. The minimum number of divisions on its circular scale required to measure 5μm diameter of wire is : **[JEE Main-2019_Jan.]**

(1) 50 (2) 100 (3) 200 (4) 500

ER0095

20. In a simple pendulum experiment for determination of acceleration due to gravity (g), time taken for 20 oscillations is measured by using a watch of 1 second least count. The mean value of time taken comes out to be 30 s. The length of pendulum is measured by using a meter scale of least count 1 mm and the value obtained is 55.0 cm. The percentage error in the determination of g is close to :-

[JEE Main-2019_April]

(1) 0.7% (2) 0.2% (3) 3.5% (4) 6.8%

ER0096

21. A simple pendulum is being used to determine th value of gravitational acceleration g at a certain place. Th length of the pendulum is 25.0 cm and a stop watch with 1s resolution measures the time taken for 40 oscillations to be 50 s. The accuracy in g is : **[JEE Main-2020_Jan]**

(1) 3.40% (2) 5.40% (3) 4.40% (4) 2.40%

ER0097

22. The least count of the main scale of a vernier callipers is 1 mm. Its vernier scale is divided into 10 divisions and coincide with 9 divisions of the main scale. When jaws are touching each other, the 7^{th} division of vernier scale coincides with a division of main scale and the zero of vernier scale is lying right side of the zero of main scale. When this vernier is used to measure length of a cylinder the zero of the vernier scale between 3.1 cm and 3.2 cm and 4^{th} VSD coincides with a main scale division. The length of the cylinder is : (VSD is vernier scale division) **[JEE Main-2020_Sep.]**

(1) 3.21 cm (2) 2.99 cm (3) 3.2 cm (4) 3.07 cm

ER0098

23. Using screw gauge of pitch 0.1 cm and 50 divisions on its circular scale, the thickness of an object is measured. It should correctly be recorded as : **[JEE Main-2020_Sep.]**

(1) 2.123 cm (2) 2.125 cm (3) 2.121 cm (4) 2.124 cm

ER0099

24. A physical quantity z depends on four observables a, b, c and d, as $z = \dfrac{a^2 b^{\frac{2}{3}}}{\sqrt{c}\, d^3}$. The percentage of error in the measurement of a, b, c and d 2%, 1.5%, 4% and 2.5% respectively. The percentage of error in z is:

[JEE Main-2020_Sep.]

(1) 12.25% (2) 14.5% (3) 16.5% (4) 13.5%

ER0100

25. The density of a solid metal sphere is determined by measuring its mass and its diameter. The maximum error in the density of the sphere is $\left(\dfrac{x}{100}\right)\%$. If the relative errors in measuring the mass and the diameter are 6.0% and 1.5% respectively, the value of x is . **[JEE Main-2020_Sep.]**

ER0101

26. A student measuring the diameter of a pencil of circular cross-section with the help of a vernier scale records the following four readings 5.50 mm, 5.55 mm, 5.45 mm; 5.65 mm. The average of these four readings is 5.5375 mm and the standard deviation of the data is 0.07395 mm. The average diameter of the pencil should therefore be recorded as: **[JEE Main-2020_Sep.]**

(1) (5.5375 ± 0.0739) mm (2) (5.538 ± 0.074) mm

(3) (5.54 ± 0.07) mm (4) (5.5375 ± 0.0740) mm

ER0102

EXERCISE - JA

1. Students I, II and III perform an experiment for measuring the acceleration due to gravity (g) using pendulum. They use different lengths of the pendulum and/or record time for different number of oscillations. The observations are shown in the table. **[JEE 2008]**

Least count for length = 0.1 cm Least count for time = 0.1 s

Student	Length of the Pendulum (cm)	Number of oscilltions (n)	Total time for (n) oscillations (s)	Time period (s)
I	64.0	8	128.0	16.0
II	64.0	4	64.0	16.0
III	20.0	4	36.0	9.0

If E_I, E_{II} and E_{III} are the percentage error in g, i.e., $\left(\frac{\Delta g}{g}\times 100\right)$ for students I, II and III, respectively,

(A) $E_I = 0$ (B) E_I is minimum

(C) $E_I = E_{II}$ (D) E_{II} is maximum

ER0074

2. A student uses a simple pendulum of exactly 1m length to determine g, the acceleration due to gravity. He uses a stopwatch with the least count of 1 sec for this and records 40 seconds for 20 oscillations. For this observation, which of the following statement(s) is (are) true? **[JEE 2010]**

(A) Error ΔT in measuring T, the time period is 0.05 seconds

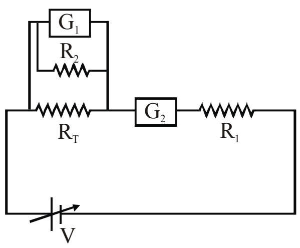
(B) Error ΔT in measuring T, the time period is 1 second

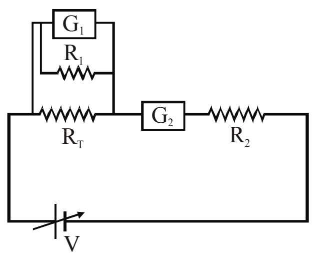
(C) Percentage error in the determination of g is 5%

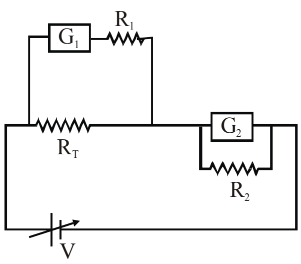
(D) Percentage error in the determination of g is 2.5%

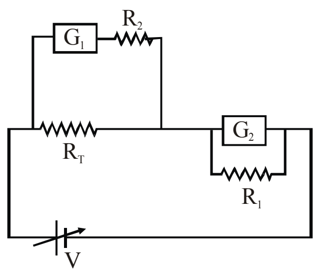
ER0075

3. To verify Ohm's law, a student is provided with a test resistor R_T, a high resistance R_1, a small resistance R_2, two identical galvanometers G_1 and G_2, and a variable voltage source V. The correct circuit to carry out the experiment is :– **[JEE 2010]**

(A)


(B)


(C)


(D)


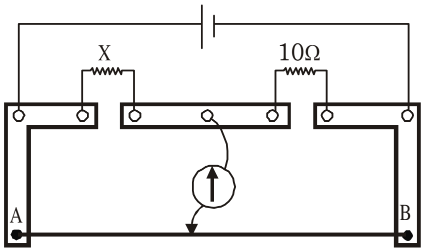
ER0076

4. A Vernier callipers has 1 mm marks on the main scale. It has 20 equal divisions on the Vernier scale which match with 16 main scale divisions. For this Vernier calipers, the least count is **[JEE 2010]**

(A) 0.02 mm (B) 0.05 mm (C) 0.1 mm (D) 0.2 mm

ER0077

5. A meter bridge is set-up as shown, to determine an unknown resistance 'X' using a standard 10 ohm resistor. The galvanometer shows null point when tapping-key is at 52 cm mark. The end-corrections are 1 cm and 2 cm respectively for the ends A and B. The determined value of 'X' is **[JEE 2011]**



(A) 10.2 ohm (B) 10.6 ohm (C) 10.8 ohm (D) 11.1 ohm

ER0078

6. The density of a solid ball is to be determined in an experiment. The diameter of the ball is measured with a screw gauge, whose pitch is 0.5 mm and there are 50 divisions on the circular scale. The reading on the main scale is 2.5 mm and that on the circular scale is 20 divisions. If the measured mass of the ball has a relative error of 2%, the relative percentage error in the density is **[JEE 2011]**

(A) 0.9% (B) 2.4% (C) 3.1% (D) 4.2%

ER0079

7. In the determination of Young's modulus $\left(Y = \frac{4MLg}{\pi \ell d^2}\right)$ by using Searle's method, a wire of length L = 2m and diameter d = 0.5 mm is used. For a load M = 2.5 kg, an extension l = 0.25 mm in the length of the wire is observed. Quantities d and l are measured using a screw gauge and a micrometer, respectively. They have the same pitch of 0.5 mm. The number of divisions on their circular scale is 100. The contributions to the maximum probable error of the Y measurement

(A) due to the errors in the measurements of d and l are the same.

(B) due to the error in the measurement of d is twice that due to the error in the measurement of l.

(C) due to the error in the measurement of l is twice that due to the error in the measurement of d.

(D) due to the error in the measurement of d is four times that due to the error in the measurement of l.

[JEE 2012]

ER0080

8. The diameter of a cylinder is measured using a Vernier callipers with no zero error. It is found that the zero of the Vernier scale lies between 5.10 cm and 5.15 cm of the main scale. The Vernier scale has 50 divisions equivalent to 2.45 cm. The 24th division of the Vernier scale excatly coincides with one of the main scale divisions. The diameter of the cylinder is :- **[JEE-Advance 2013]**

(A) 5.112 cm (B) 5.124 cm (C) 5.136 cm (D) 5.148 cm

ER0081

9. Using the expression 2d sin $\theta = \lambda$, one calculates the values of d by measuring the corresponding angles θ in the range 0 to 90°. The wavelength λ is exactly known and the error in θ is constant for all values of θ. As θ increases from 0° :- **[JEE-Advance 2013]**

(A) the absolute error in d remains constant

(B) the absolute error in d increases

(C) the fractional error in d remains constant

(D) the fractional error in d decreases

ER0082

10. During Searle's experiment, zero of the Vernier scale lies between 3.20×10^{-2} m and 3.25×10^{-2}m of the main scale. The 20^{th} division of the Vernier scale exactly coincides with one of the main scale divisions. When an additional load of 2 kg is applied to the wire, the zero of the Vernier scale still lies between 3.20×10^{-2} m and 3.25×10^{-2} m of the main scale but now the 45^{th} division of Vernier scale coincides with one of the main scale divisions. The length of the thin metallic wire is 2m and its cross-sectional area is 8×10^{-7} m^2. The least count of the Vernier scale is 1.0×10^{-5} m. The maximum percentage error in the Young's modulus of the wire is. **[JEE-Advance 2014]**

ER0083

11. Consider a Vernier callipers in which each 1 cm on the main scale is divided into 8 equal divisions and a screw gauge with 100 divisions on its circular scale. In the Vernier callipers, 5 divisions of the Vernier scale coincide with 4 divisions on the main scale and in the screw gauge, one complete rotation of the circular scale moves it by two divisions on the linear scale. Then :

[JEE-Advance 2015]

(A) If the pitch of the screw gauge is twice the least count of the Vernier callipers, the least count of the screw gauge is 0.01 mm.

(B) If the pitch of the screw gauge is twice the least count of the Vernier callipers, the least count of the screw gauge is 0.005 mm.

(C) If the least count of the linear scale of the screw gauge is twice the least count of the Vernier callipers, the least count of the screw gauge is 0.01 mm.

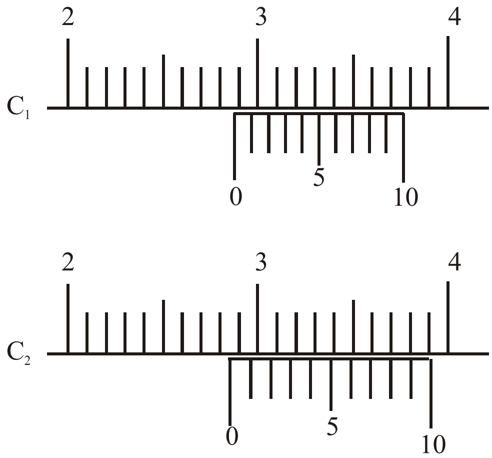
(D) If the least count of the linear scale of the screw gauge is twice the least count of the Vernier callipers, the least count of the screw gauge is 0.005 mm.

ER0084

12. The energy of a system as a function of time t is given as $E(t) = A^2 \exp(-\alpha t)$, where $\alpha = 0.2 s^{-1}$. The measurement of A has an error of 1.25%. If the error in the measurement of time is 1.50%, the percentage error in the value of E(t) at t = 5 s is. **[JEE-Advance 2015]**

ER0085

13. There are two vernier calipers both of which have 1 cm divided into 10 equal divisions on the main scale. The Vernier scale of one of the calipers (C_1) has 10 equal divisions that correspond to 9 main scale divisions. The Vernier scale of the other caliper (C_2) has 10 equal divisions that correspond to 11 main scale divisions. The readings of the two calipers are shown in the figure. The measured values (in cm) by calipers C_1 and C_2 respectively, are **[JEE-Advance 2016]**



(A) 2.87 and 2.86 (B) 2.87 and 2.87 (C) 2.87 and 2.83 (D) 2.85 and 2.82

ER0086

14. In an experiment to determine the acceleration due to gravity g, the formula used for the time period of a periodic motion is $T = 2\pi\sqrt{\frac{7(R-r)}{5g}}$. The values of R and r are measured to be (60 ± 1) mm and (10 ± 1) mm, respectively. In five successive measurements, the time period is found to be 0.52 s, 0.56 s, 0.57s, 0.54 s and 0.59 s. The least count of the watch used for the measurement of time period is 0.01 s. Which of the following statement(s) is(are) true ? **[JEE-Advance 2016]**

(A) The error in the measurement of r is 10%

(B) The error in the measurement of T is 3.57 %

(C) The error in the measurement of T is 2%

(D) The error in the determined value of g is 11%

ER0087

15. A person measures the depth of a well by measuring the time interval between dropping a stone and receiving the sound of impact with the bottom of the well. The error in his measurement of time is $\delta T = 0.01$ second and he measures the depth of the well to be L = 20 meters. Take the acceleration due to gravity $g = 10\ ms^{-2}$ and the velocity of sound is $300\ ms^{-1}$. Then the fractional error in the measurement, $\delta L/L$, is closest to **[JEE-Advance 2017]**

(A) 0.2 % (B) 5 % (C) 3 % (D) 1 %

ER0088

PARAGRAPH "A"

If the measurement errors in all the independent quantities are known, then it is possible to determine the error in any dependent quantity. This is done by the use of series expansion and truncating the expansion at the first power of the error. For example, consider the relation z = x/y. If the errors in x, y and z are Δx, Δy and Δz, respectively, then **[JEE-Advance 2018]**

$$z \pm \Delta z = \frac{x \pm \Delta x}{y \pm \Delta y} = \frac{x}{y}\left(1 \pm \frac{\Delta x}{x}\right)\left(1 \pm \frac{\Delta y}{y}\right)^{-1}.$$

The series expansion for $\left(1 \pm \frac{\Delta y}{y}\right)^{-1}$, to first power in Δy/y, is $1 \mp (\Delta y / y)$. The relative errors in independent variables are always added. So the error in z will be

$$\Delta z = z\left(\frac{\Delta x}{x} + \frac{\Delta y}{y}\right).$$

The above derivation makes the assumption that $\frac{\Delta x}{x} << 1, \frac{\Delta y}{y} << 1$. Therefore, the higher powers of these quantities are neglected.

(There are two questions based on Paragraph "A", the question given below is one of them)

16. Consider the ratio $r = \frac{(1-a)}{(1+a)}$ to be determined by measuring a dimensionless quantity a. If the error in the measurement of a is Δa(Δa/a << 1), then what is the error Δr in determining r ?

(A) $\frac{\Delta a}{(1+a)^2}$ (B) $\frac{2\Delta a}{(1+a)^2}$

(C) $\frac{2\Delta a}{(1-a^2)}$ (D) $\frac{2a\Delta a}{(1-a^2)}$

ER0089

PARAGRAPH "A"

If the measurement errors in all the independent quantities are known, then it is possible to determine the error in any dependent quantity. This is done by the use of series expansion and truncating the expansion at the first power of the error. For example, consider the relation z = x/y. If the errors in x, y and z are Δx, Δy and Δz, respectively, then

$$z \pm \Delta z = \frac{x \pm \Delta x}{y \pm \Delta y} = \frac{x}{y}\left(1 \pm \frac{\Delta x}{x}\right)\left(1 \pm \frac{\Delta y}{y}\right)^{-1}.$$

The series expansion for $\left(1 \pm \frac{\Delta y}{y}\right)^{-1}$, to first power in Δy/y, is $1 \mp (\Delta y / y)$. The relative errors in independent variables are always added. So the error in z will be

$$\Delta z = z\left(\frac{\Delta x}{x} + \frac{\Delta y}{y}\right).$$

The above derivation makes the assumption that $\frac{\Delta x}{x} << 1, \frac{\Delta y}{y} << 1$. Therefore, the higher powers of these quantities are neglected.

(There are two questions based on Paragraph "A", the question given below is one of them)

17. In an experiment the initial number of radioactive nuclei is 3000. It is found that 1000 ± 40 nuclei decayed in the first 1.0 s. For $|x| << 1$, In $(1 + x) = x$ up to first power in x. The error $\Delta\lambda$, in the determination of the decay constant λ, in s^{-1}, is :-

(A) 0.04 (B) 0.03 (C) 0.02 (D) 0.01

ER0090

18. A steel wire of diameter 0.5 mm and Young's modulus 2×10^{11} N m^{-2} carries a load of mass M. The length of the wire with the load is 1.0 m. A vernier scale with 10 divisions is attached to the end of this wire. Next to the steel wire is a reference wire to which a main scale, of least count 1.0 mm, is attached. The 10 divisions of the vernier scale correspond to 9 divisions of the main scale. Initially, the zero of vernier scale coincides with the zero of main scale. If the load on the steel wire is increased by 1.2kg, the vernier scale division which coincides with a main scale division is....... Take $g = 10$ ms^{-2} and $\pi = 3.2$.

[JEE-Advance 2018]

ER0091

19. An optical bench has 1.5 m long scale having four equal divisions in each cm. While measuring the focal length of a convex lens, the lens is kept at 75 cm mark of the scale and the object pin is kept at 45 cm mark. The image of the object pin on the other side of the lens overlaps with image pin that is kept at 135 cm mark. In this experiment, the percentage error in the measurement of the focal length of the lens is________.

[JEE-Advance 2019]

ER0092

20. Two capacitors with capacitance values $C_1 = 2000 \pm 10$ pF and $C_2 = 3000 \pm 15$ pF are connected in series. The voltage applied across this combination is $V = 5.00 \pm 0.02$ V. The percentage error in the calculation of the energy stored in this combination of capacitors is _______. **[JEE-Advance 2020]**

ER0103

ANSWER KEY

EXERCISE (S)

1. Ans. (A) 3, (B) 3, (C) 4, (D) 4, (E) 3, (F) 5, (G) 2, (H) 4
2. Ans. (A) 711, (B) 0.7, (C) 1.0×10^3, (D) 20.0
3. Ans. (i) 0.4, (ii) 14 **4. Ans.** 3.07 cm **5. Ans.** (i) x = –0.7 msd, (ii) 6, 1
6. Ans. L.C. = $l\left[\frac{1-\cos\theta}{\cos\theta}\right]$ **7. Ans.** 2.84 mm **8. Ans.** $R_t = 3.64$ mm
9. Ans. 5.5 ± 0.1 cm **10. Ans.** CD, AB, EF **11. Ans.** $v = (3.4 \pm 0.4)$ m/s
12. Ans. $S = (1.2 \pm 0.2)$ cm **13. Ans.** $R_8 = 15.0\ \Omega \pm 2\%$, $R_p = 3.3\ \Omega \pm 3\%$
14. Ans. 4.8 g/cm^3 **15. Ans.** 9% **16. Ans.** $\Delta Y = 0.0489Y = 1.1 \times 10^{10}$ N/m^2
17. Ans. 2.6 cm^2 (in two significant figures) **18. Ans.** 14%, 0.53
19. Ans. $5\pi/18\%$ **20. Ans.** 1.8 /(N+2) **21. Ans.** $\frac{a}{n+1}$
22. Ans. T = 2.62 s. 0.01 s, – 0.06 s, – 0.20 s, 0.09 s, 0.18 s, Average absolute error = 0.11 s, 4.2 %
23. Ans. 2.66 g/cm^3

EXERCISE (O)

1. Ans. (D) **2. Ans. (A)** **3. Ans. (C)** **4. Ans. (A,B,C)** **5. Ans. (A)** **6. Ans. (A)**
7. Ans. (D) **8. Ans. (A)** **9. Ans. (A)** **10. Ans. (A)** **11. Ans. (A)** **12. Ans. (B)**
13. Ans. (B) **14. Ans. (A)** **15. Ans. (B)** **16. Ans. (B)** **17. Ans. (D)** **18. Ans. (D)**
19. Ans. (C) **20. Ans. (B)** **21. Ans. (A)** **22. Ans. (D)** **23. Ans. (C)** **24. Ans. (C)**
25. Ans. (D) **26. Ans. (B)** **27. Ans. (A,C)** **28. Ans. (A or B)**

EXERCISE-JM

1. Ans. (1) **2. Ans. (4)** **3. Ans. (3)** **4. Ans. (3)** **5. Ans. (2)** **6. Ans. (4)**
7. Ans. (4) **8. Ans. (2)** **9. Ans. (3)** **10. Ans. (4)** **11. Ans. (4)** **12. Ans. (3)**
13. Ans. (2) **14. Ans. (2)** **15. Ans. (4)** **16. Ans. (2)** **17. Ans. (2)** **18. Ans. (1)**
19. Ans. (3) **20. Ans. (4)** **21. Ans. (3)** **22. Ans. (4)** **23. Ans. (4)** **24. Ans. (2)**
25. Ans. (1050.00) **26. Ans. (3)**

EXERCISE - JA

1. Ans. (B) **2. Ans. (A,C)** **3. Ans. (C)** **4. Ans. (D)** **5. Ans. (B)** **6. Ans. (C)**
7. Ans. (A) **8. Ans. (B)** **9. Ans. (D)** **10. Ans. 4** **11. Ans. (B,C)** **12. Ans. 4**
13. Ans. (C) **14. Ans. (A, B, D)** **15. Ans. (D)** **16. Ans. (B)** **17. Ans. (C)**
18. Ans. 3 [2.99, 3.01] **19. Ans. (1.35 to 1.45)** **20. Ans. 1.30**

Important Notes

Chapter Contents 04

SEMICONDUCTOR

Important Notes

KEY CONCEPTS

ENERGY BANDS IN SOLIDS

Based on Pauli's exclusion principle

In an isolated atom electrons present in energy level but in solid, atoms are not isolated, there is interaction among each other, due to this energy level splited into different energy levels. Quantity of these different energy levels depends on the quantity of interacting atoms. Splitting of sharp and closely compact energy levels result into energy band. This is discrete in nature. Order of energy levels in a band is 10^{23} and their energy difference = 10^{-23} eV.

Energy Band

Range of energy possessed by electron in a solid is known as energy band.

Valence Band (VB)

Range of energies possessed by valence electron is known as valence band.

(a) Have bonded electron.

(b) No flow of current due to such electron.

(c) Always fulfill by electron.

Conduction Band (CB)

Range of energies possessed by free electron is known as conduction band.

(a) It has conducting electrons.

(b) Current flows due to such electrons.

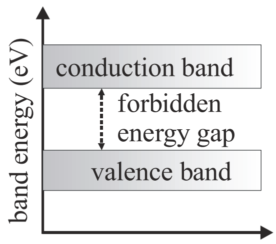
(c) If conduction band is fully empty then current conduction is not possible.

(d) Electrons may exist or not in it.

Forbidden Energy gap (FEG) (ΔEg)

$$\Delta E_g = (C\,B)_{min} - (V\,B)_{max}$$

Energy gap between conduction band and valence band, where no free electron can exist.



- Width of forbidden energy gap depends upon the nature of substance.
- Width is more, then valence electrons are strongly attached with nucleus
- Width of forbidden energy gap is represented in eV.
- As temperature increases forbidden energy gap decreases (very slightly).

CLASSIFICATION OF CONDUCTORS, INSULATORS AND SEMICONDUCTOR : -

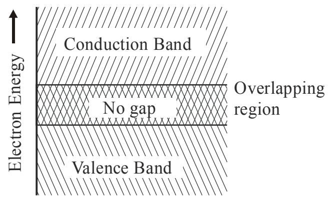
On the basis of the relative values of electrical conductivity and energy bands the solids are broadly classified into three categories

(i) Conductor (ii) Semiconductor (iii) Insulator

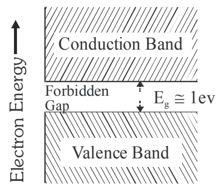
Comparison between conductor, semiconductor and insulator :

Properties	Conductor	Semiconductor	Insulator
Resistivity	$10^{-2} - 10^{-8}\ \Omega m$	$10^{-5} - 10^{6}\ \Omega m$	$10^{11} - 10^{19}\ \Omega m$
Conductivity	$10^{2} - 10^{8}$ mho/m	$10^{5} - 10^{-6}$ mho/m	$10^{-11} - 10^{-19}$ mho/m
Temp. Coefficient of resistance (α)	Positive	Negative	Negative
Current	Due to free electrons	Due to electrons and holes	No current

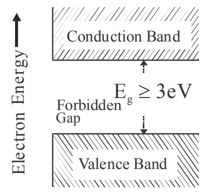
Energy band diagram



Conductor



Semi conductor

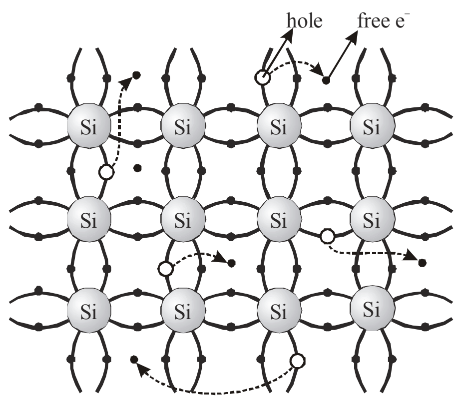


Insulator

Properties	Conductor	Semiconductor	Insulator
Forbidden energy gap	$\cong$ 0eV	$\cong$ 1eV	$\geq$ 3eV
Example :	Pt, Al, Cu, Ag	Ge, Si, GaAs, GaF_2	Wood, plastic, Diamond, Mica

CONCEPT OF "HOLES" IN SEMICONDUCTORS

Due to external energy (temp. or radiation) when electron goes from valence band to conduction band (i.e. bonded electrons becomes free) a vacancy of free e^- creats in valence band,



which has same charge as electron but positive. This positively charged vaccancy is termed as hole and shown in figure.

- It is deficiency of electron in VB.
- It acts as positive charge carrier.
- It's effective mass is more than electron.
- It's mobility is less than electron.

Note : Hole acts as virtual charge carrier, although it has no physical significance.

- Number of electrons reaching from VB to CB at temperature T kelvin

$$\boxed{n = A\,T^{3/2}\, e^{-\frac{E_g}{2kT}} = AT^{3/2}\exp\left[-\frac{E_g}{2kT}\right]}$$

where

k = Boltzmann constant = 1.38×10^{-23} J/K T = absolute temperature

A = constant E_g = energy gap between CB and VB

- In silicon at room temperature out of 10^{12} Si atoms only one electron goes from VB to CB.
- In germanium at room temperature out of 10^{9} Ge atoms only one electron goes from VB to CB.

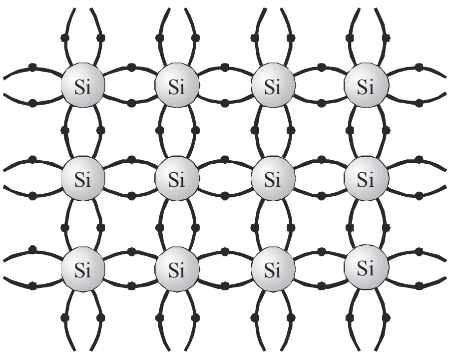
EFFECT OF TEMPERATURE ON SEMICONDUCTOR

At absolute zero kelvin temperature

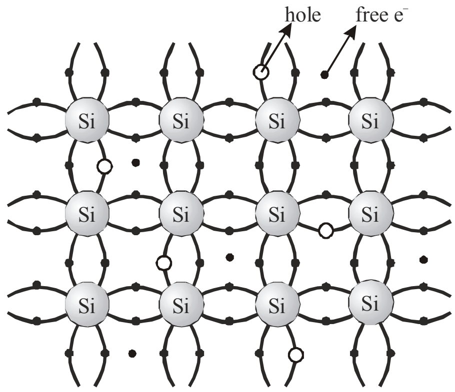
At this temperautre covalent bonds are very strong and there are no free electrons and semiconductor behaves as perfect insulator.

Above absolute temperature

With increase in temperature few valence electrons jump into conduction band and hence it behaves as poor conductor.



at 0 K
Valence band fully filled
Conduction band fully empty



at high temperature
Valence band partially empty
Conduction band partially filled

EFFECT OF IMPURITY IN SEMICONDUCTOR

Doping is a method of addition of "desirable" impurity atoms to pure semiconductor to increase conductivity of semiconductor. or

Doping is a process of deliberate addition of a desirable impurity atoms to a pure semiconductor to modify its properties in controlled manner.

Added impurity atoms are called dopants.

The impurity added may be ≈ 1 part per million (ppm).

- The dopant atom should take the position of semiconductor atom in the lattice.
- The presence of the dopant atom should not distort the crystal lattice.
- The size of the dopant atom should be almost the same as that of the crystal atom.
- The concentration of dopant atoms should not be large (not more than 1% of the crystal atom).

It is to be noted that the doping of a semiconductor increases its electrical conductivity to a great extent.

- The concentration of dopant atoms be very low, doping ratio is vary from impure : pure :: $1 : 10^6$ to $1 : 10^{10}$ In general it is $1 : 10^8$
- There are two main method of doping.
  (i) Alloy method (ii) Diffusion method (The best)
- The size of dopant atom (impurity) should be almost the same as that of crystal atom. So that crystalline structure of solid remain unchanged.

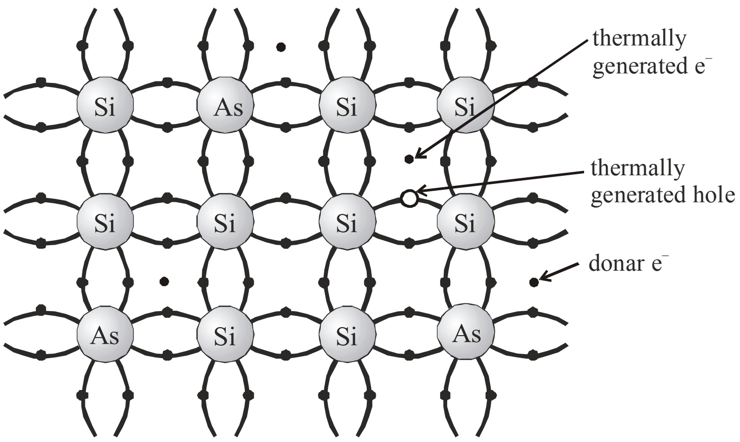
CLASSIFICATION OF SEMICONDUCTOR

SEMICONDUCTOR

- Intrinsic semiconductor
  - (pure form of Ge, Si)
  - $n_e = n_h = n_i$
- Extrinsic semiconductor (doped semicondutor)
  - N-type
    - pentavalent impurity
    - (P, As, Sb etc.)
    - donar impurity (N_D)
    - $n_e >> n_h$
  - P-type
    - trivalent impurity
    - (Ga, B, In, Al)
    - acceptor impurity (N_A)
    - $n_h >> n_e$

N type semiconductor

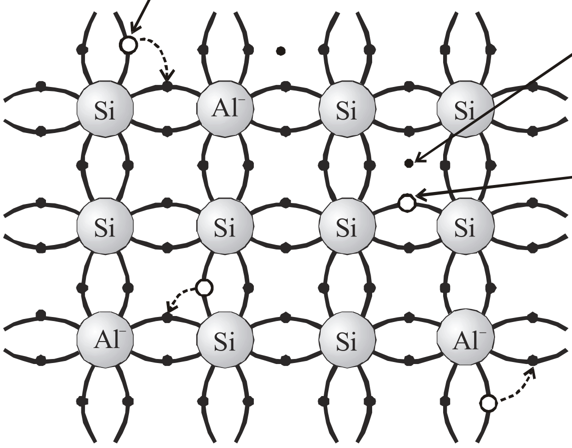
When a pure semiconductor (Si or Ge) is doped by pentavalent impurity (P, As, Sb, Bi) then four electrons out of the five valence electrons of impurity take part, in covalent bonding, with four silicon atoms surrounding it and the fifth electron is set free. These impurity atoms which donate free e^- for conduction are called as Donar impurity (N_D). Due to donar impurity free e^- increases very much so it is called as "N" type semiconductor. By donating e^- impurity atoms get positive charge and hence known as "Immobile Donar positive Ion". In N-type semiconductor free e^- are called as "majority" charge carriers and "holes" are called as "minority" charge carriers.



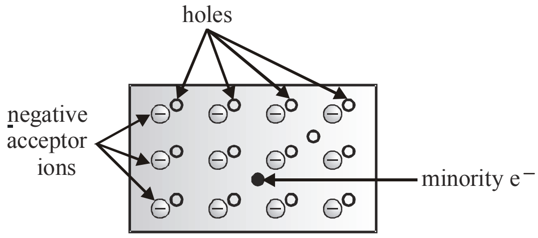
N-type semiconducting crystal

P type semiconductor

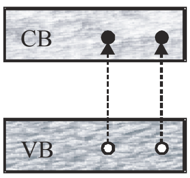
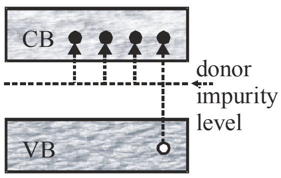
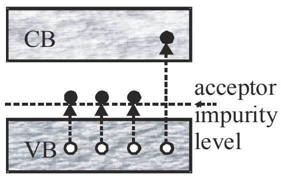
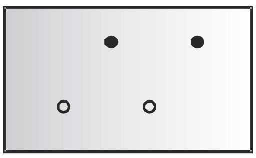
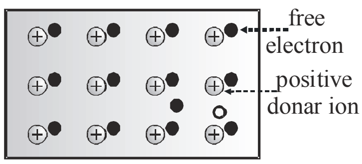
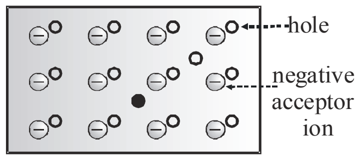
When a pure semiconductor (Si or Ge) is doped by trivalent impurity (B, Al, In, Ga) then outer most three electrons of the valence band of impurity take part, in covalent bonding with four silicon atoms surrounding it and except one electron from semiconductor and make hole in semiconductor. These impurity atoms which accept bonded e^- from valance band are called as Acceptor impurity (N_A). Here holes increases very much so it is called as "P" type semiconductor and impurity ions known as "Immobile Acceptor negative Ion". In P-type semiconductor free e^- are called as minority charge carries and holes are called as majority charge carriers.



P-type semiconducting crystal



P-type semiconductor

	Intrinsic Semiconductor	N-type (Pentavalent impurity)	P-type(Trivalent impurity)
1.			
2.			
3.	Current due to electron and hole	Mainly due to electrons	Mainly due to holes
4.	$n_e = n_h = n_i$	$n_h << n_e$ ($N_D \simeq n_e$)	$n_h >> n_e$ ($N_A \simeq n_h$)
5.	$I = I_e + I_h$	$I \simeq I_e$	$I \simeq I_h$
6.	Entirely neutral	Entirely neutral	Entirely neutral
7.	Quantity of electrons and holes are equal	Majority - Electrons Minority - Holes	Majority - Holes Minority - Electrons

Mass action Law

In semiconductors due to thermal effect, generation of free e^- and hole takes place.

Apart from the process of generation, recombination also occurs simultaneously, in which free e^- further recombine with hole.

At equilibrium rate of generation of charge carries is equal to rate of recombination of charge carrier.

The recombination occurs due to e^- colliding with a hole, larger value of n_e or n_h, higher is the probability of their recombination.

Hence for a given semiconductor rate of recombination $\propto n_e \times n_h$

so rate of recombination = R $n_e \times n_h$ R = recombination coefficient,

The value of R remains constant for a solid, according to the law of thermodynamics until crystalline lattice structure remains same.

For intrinsic semiconductor $n_e = n_h = n_i$

so rate of recombination = R n_i^2

$$R\,n_e \times n_h = R\,n_i^2 \quad \Rightarrow \quad n_i^2 = n_e \times n_h$$

Under thermal equilibrium, the product of the concentration 'n_e' of free electrons and the concentration n_h of holes is a constant and it is independent of the amount of doping by acceptor and donor impurities.

Thus from mass action law $\boxed{n_e \times n_h = n_1^2}$

Electron-hole Recombination :

It is necessarly to complete a band that electron is shared from neighbouring atoms or it may also be received from conduction band. In the second case electron recombines with the hole of valnce band. This process is known as electron-hole recombination.

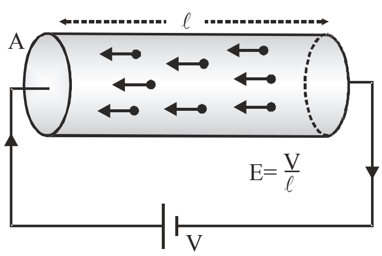
The breaking of bands or generation of electron-hole pairs, and completion of bands due to recombination is taking place continuously.

At equilibrium, the rate of generation becomes equal to the rate of recombination, giving a fixed number of free electrons and holes.

RESISTIVITY AND CONDUCTIVITY OF SEMICONDUCTOR

Conduction in conductor

Relation between current (I) and drift velocity (v_d)



$I = neAv_d$ n = number of electron in unit volume

A= cross sectional area

current density $J = \dfrac{I}{A}$ amp/m^2 = ne v_d drift velocity of electron $v_d = \mu E$

$J = ne\,\mu E$ $J = \sigma E$

Conductivity $\sigma = ne\mu = 1/\rho$ ρ = Resistivity

Mobility $\mu = \dfrac{v_d}{E}$

Conduction in Semiconductor

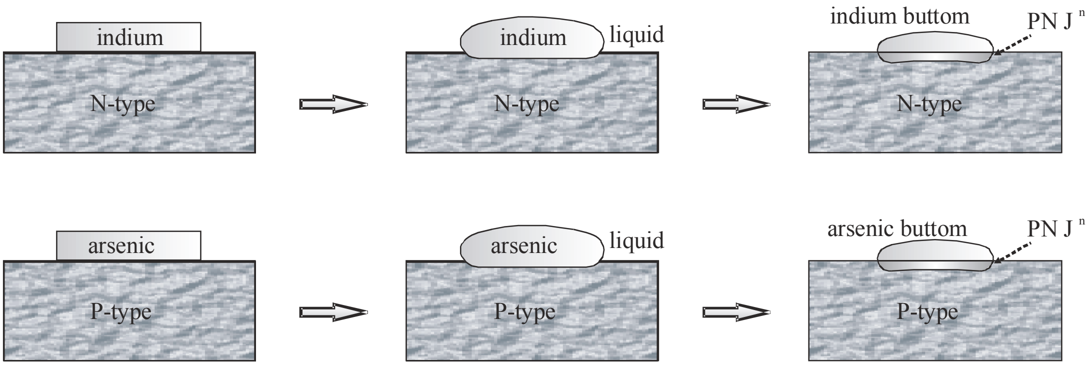
Intrinsic semiconductor	P - type	N - type
$n_e = n_h$	$n_h >> n_e$	$n_e >> n_h$
$J = ne\,[\,v_e + v_h]$	$J \cong e\,n_h\,v_h$	$J \cong e\,n_e\,v_e$
$\sigma = \frac{1}{\rho} = en\,[\,\mu_e + \mu_h\,]$	$\sigma = \frac{1}{\rho} \cong e\,n_h\,\mu_h$	$\sigma = \frac{1}{\rho} \cong e\,n_e\,\mu_e$

P - N JUNCTION

Techniques for making P-N junction

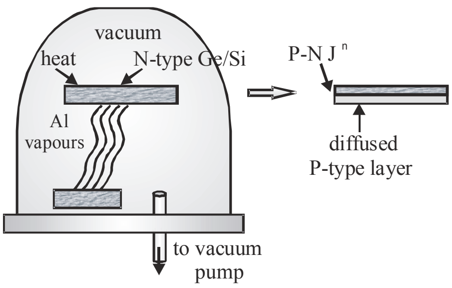
(i) Alloy Method or Alloy Junction

Here a small piece of III group impurity like indium is placed over n–Ge or n–Si and melted as shown in figure ultimetely P – N junction form.



(ii) Diffusion Junction :-

A heated P–type semiconductor is kept in pentavalent impurity vapours which diffuse into P–type semiconductor as shown and make P–N junction.



(iii) Vapour deposited junction or epitaxial junction :

If we want to grow a layer of n–Si or p–Si then p–Si wafer is kept in an atmosphere of Silane (a silicon compound which dissociates into Si at high temperatures) plus phosphorous vapours. On craking of silane at high temperature a fresh layer on n–Si grows on p–Si giving the "P–N junction". Since this junction growth is layer by so it is also referred as layer growth or epitaxial junction formation of P–N junction.

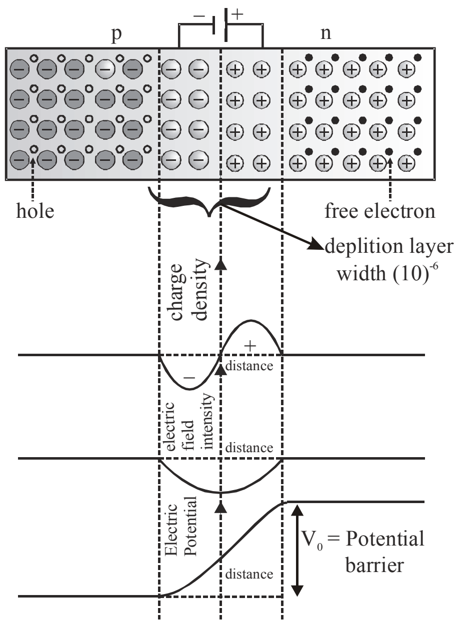
Description of P-N Junction without applied voltage or bias

Given diagram shows a P–N junction immediately after it is formed.

P region has mobile majority holes and immobile negatively charged impurity ions.

N region has mobile majority free electrons and immobile positively charged impurity ions.

Due to concentration difference diffusion of holes starts from P to N side and diffusion of e^- s starts N to P side.



Due to this a layer of only positive (in N side) and negative (in P–side) started to form which generate an electric field (N to P side) which oppose diffusion process, during diffusion magnitude of electric field increases due to this diffusion it gradually decreased and ultimately stope.

The layer of immobile positive and negative ions, which have no free electrons and holes called as **depletion layer** as shown in diagram.

- **Width of depletion layer $\cong$ 10^{-6} m**

  (a) As doping increases depletion layer decreases

  (b) As temperature is increased depletion layer also increases.

  (c) P-N junction $\rightarrow$ nonohmic, due to nonlinear relation between I and V.

- **Potential Barrier or contact potential**

  Ge $\longrightarrow$ 0.3 V   Si $\longrightarrow$ 0.7 V

- Electric field, produce due to potential barrier $E = \frac{V}{d} = \frac{0.5}{10^{-6}} \Rightarrow E \cong 10^5$ V/m

  This field prevents the respective majority carrier from crossing barrier region

DIFFUSION AND DRIFT CURRENT

(1) Diffusion current – P to N side   (2) Drift current – N to P side

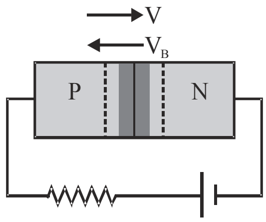
If there is no biasing diffusion current = drift current

So total current is zero

BEHAVIOUR OF P–N JUNCTION WITH AN EXTERNAL VOLTAGE APPLIED OR BIAS

Forward Bias

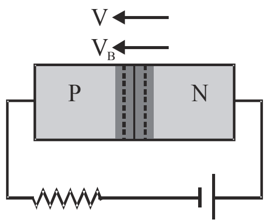
If we apply a voltage "V" such that P–side is positive and N–side is negative as shown in diagram.



The applied voltage is opposite to the junction barrier potential.Due to this effective potential barrier decreases, junction width also decreases, so more majority carriers will be allowed to flow across junction. It means the current flow in principally due to majority charge carriers and it is in the order of mA called as forward Bias.

Reverse Bias

If we apply a voltage "V" such that P–side is negative and N–side is positive as shown in diagram. The applied voltage is in same direction as the junction barrier potential. Due to this effective potential barrier increase junction, width also increases, so no majority carriers will be allowed to flow across junction.



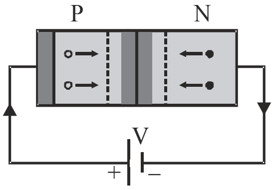
Only minority carriers will drifted. It means the current flow in principally due to minority charge carriers and is very small (in the order of μA). This bias is called as reversed Bias.

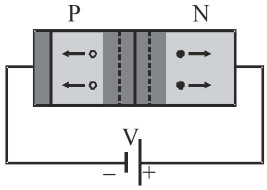
- In reverse bias, the current is very small and nearly constant with bias (termed as reverse saturation current). However interesting behaviour results in some special cases if the reverse bias is increased further beyond a certain limit, above particular high voltage breakdown of depletion layer started.
- Breakdown of a diode is of following two types :

(i) Zener breakdown (ii) Avalanche breakdown

Comparison between Forward Bias and Reverse Bias

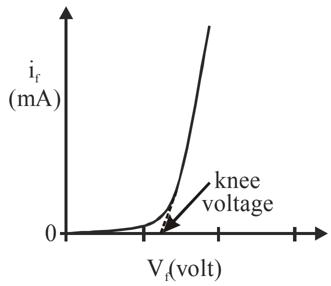
Forward Bias	**Reverse Bias**
P → positive N → negative	P → negative N → positive





Forward Bias

1. Potential Barrier reduces
2. Width of depletion layer decreases
3. P-N jn. provide very small resistance
4 Forward current flows in the circuit
5. Order of forward current is milli ampere.
6. Current flows mainly due to majority carriers.
7. Forward characteristic curves.



8. Forward resistance

$$R_f = \frac{\Delta V_f}{\Delta I_f} \cong 100\Omega$$

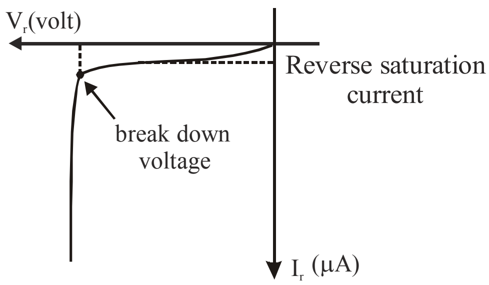
9. Order of knee or cut in voltage

Ge → 0.3 V

Si → 0.7 V

Reverse Bias

1. Potential Barrier increases.
2. Width of depletion layer increases.
3. P-N jn. provide high resistance
4. Very small current flows.
5. Order of current is micro ampere for Ge or Neno ampere for Si.
6. Current flows mainly due to minority carriers.
7. Reverse characteristic curve



8. Reverse resistance

$$R_r = \frac{\Delta V_r}{\Delta I_r} \cong 10^6\Omega$$

9. Breakdown voltage

Ge → 25 V

Si → 35 V

Special point : Generally $\frac{R_r}{R_f} = 10^3 : 1$ for Ge $\frac{R_r}{R_f} = 10^4 : 1$ for Si

Light Emitting Diode (LED):

A light emitting diode is simply a forward biased p-n junction which emits spontaneous light radiation. When forward bias is applied, the electron and holes at the junction recombine and energy released is emitted in the form of light. for visible radiation phosphorus doped GaAs is commonly used. The advantages of LEDs are:

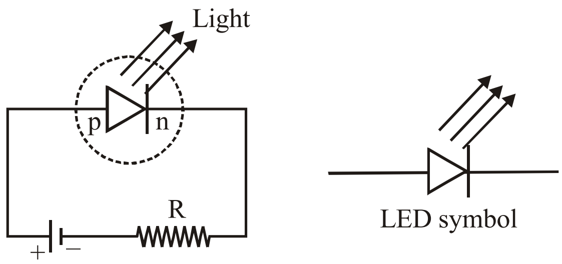
(i) Low operational voltage and less power.

(ii) Fast action with no warm up time.

(iii) Emitted light is nearly monochromatic.

(iv) They have long life.

I-V characterisitics of LED are similar to that of Si junction diode but the threshold voltages are much higher and slightly different for each colour. The reverse breakdown voltages of LED's are very low, about 5 V.

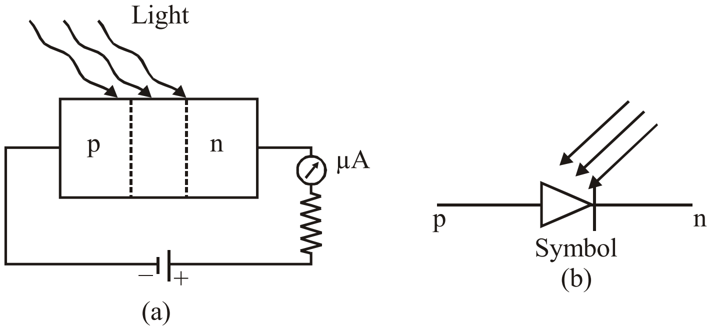


Photodiode:

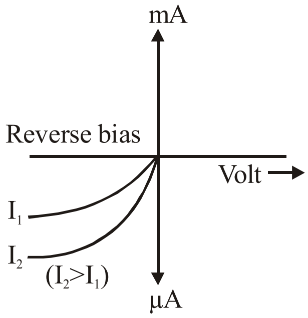
It is a reversed-biased p-n junction, illuminated by radiation. When p-n junction is reversed biased with no current, a very small reverse saturated current flows across the junction called the dark current. When the junction is illuminated with light, electron-hole pairs are created at the junction, due to which additional current begins to flow across the junction; the current is solely due to minority charge carriers.

(1) A photodiode is used in reverse bias, although in forward bias current is more than current in reverse bias because in reverse bias it is easier to observe change in current with change in light intensity.

(2) Photodiode is used to measure light intensity because reverse current increases with increase of intensity of light.

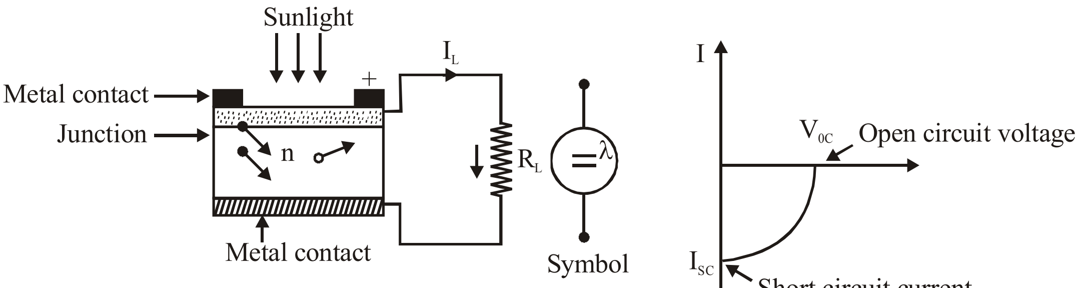


The characteristic curves of a photodiode for two different illurninatios I_1 and I_2 ($I_2 > I_1$) are shown in figure.



Solar Cell

A solar cell is a junction diode which converts tight energy'into electrical energy. A p-n junction solar cell consists of a large junction with no external biasing.



Construction and working
(a)

(b)

The surface layer of p-region is made very thin so that the incident photons may easily penetrate to reach the junction which is the active region. In an operation in the photovoltaic mode (i.e., generation of voltage due to bombardment of optical photons); the materials suitable for photocells are silicon (Si), gallium arsenide (GaAs), cadmium sulphide (CdS) and cadmium selenide (CdSe).

Working:

When photons of energy greater than band gap energy (hv >E_g) are made incident on the junction, electron-hole pairs are created which move in opposite directions due to junction field. These are collected at two sides of junction, thus producing photo-voltage; this gives rise to photocurrent. The characteristic curve of solar cell is shown in fig. Solar cells are used in satellites to recharge their batteries.

REVERSE BREAKDOWN

If the reverse bias voltage is made too high, the current through the PN junction increases rapidly at Y_z. The voltage at which this happens is called **breakdown voltage** or **Zener voltage.**

There two mechanism which causes this breakdown. One is called avalanche breakdown and other is called **Zener breakdown.**

Zener breakdown: When reverse bias is increased the electric field at then junction also increases. At some stage the electric field becomes so high that it breaks the covalent bonds creating electron, hole pairs, thus a large number of carriers are generated. This causes a large current to flow. This machanism is know as Zener breakdown.

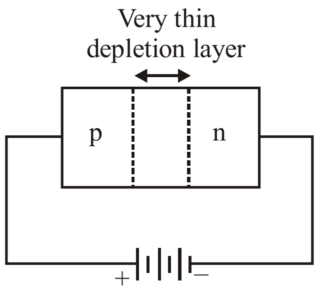
Avalanche breakdown : At high reverse voltage, due to high electric field, the rniniority charge carriers, while crossing the junction acquires very high velocities. These by collision breaks down the covalent bonds, generating more carriers. A chain reaction is established, giving rise to high current. This mechanism is called **avalanche breakdown..**

Zener Diode:

A zener diode is a specially designed heavily doped p-n junction, having a very thin depletion layer and having a very sharp breakdown voltage. It is always operated in breakdown region. Its breakdown voltage V_z is less than 6 V.

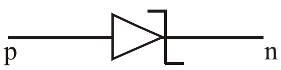
Zener Diode as a Voltage Regulator:

Zener diode may be used as a voltage regulator. The circuit of zener-diode is shown in figure.



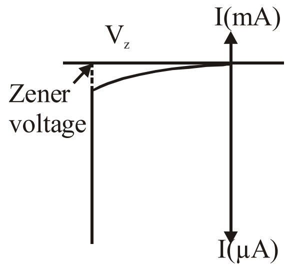
Zener diode

(a)



Symbol

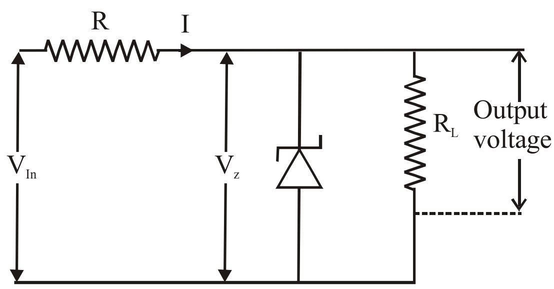
(b)



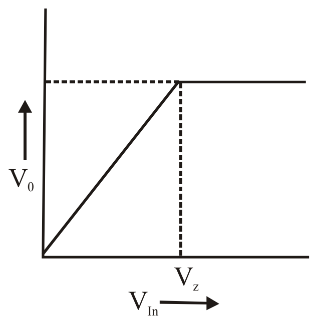
(c) characteristics

In breakdown region the equation: $V_0 = V_z = V_{in} - RI$

Clearly, when the input voltage exceeds zener voltage to keep the voltage regularity, the extra input voltage appears across series resistance R. The voltage regulation curve is shown in figure.



(d)



(e)

Zener Break down

Where covalent bonds of depletion layer, its self break, due to high electric field of very high Reverse bias voltage.

This phenomena predominant

(i) At lower voltage after "break down"

(ii) In P – N having "High doping"

(iii) P – N Jn. having thin depletion layer

Here P – N not damage paramanently

"In D.C voltage stablizer zener phenomenan is used".

Avalanche Break down

Here covalent bonds of depletion layers are bro ken by collision of "Minorities" which aquire high kinetic energy from high electric field of very-very high reverse bias voltage.

This phenomena predominant

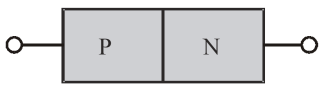
(i) At high voltage after breakdown

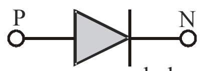
(ii) In P – N having "Low doping"

(iii) P – N Jn. having thick depletion layer

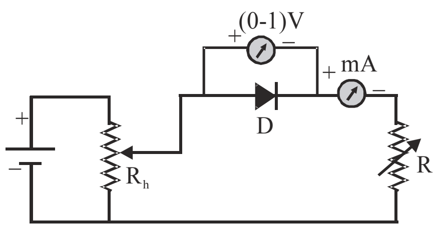
Here P – N damage peramanentaly due to "Heating effect" due to abruptly increment of minorities during repeatative collisoins.

CHARACTERISTIC CURVE OF P-N JUNCTION DIODE

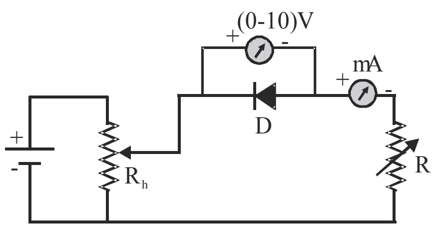




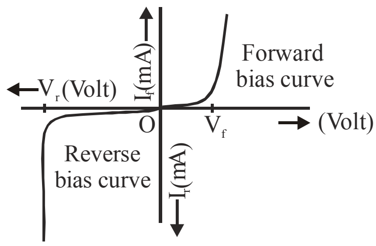
symbol



Forward bias



Reverse bias



In forward bias when voltage is increased from 0V is steps and corresponding value of current is measured, the curve comes as OB of figure. We may note that current increase very sharply after a certain voltage knee voltage. At this voltage, barrier potential is completely eliminated and diode offers a low resistance.

In reverse bias a microammeter has been used as current is very very small. When reverse voltage is increased from 0V and corresponding values of current measured the plot comes as OCD. We may note that reverse current is almost constant hence called reverse saturation current. It implies that diode resistance is very high. As reverse voltage reaches value V_B, called breakdown voltage, current increases very sharply.

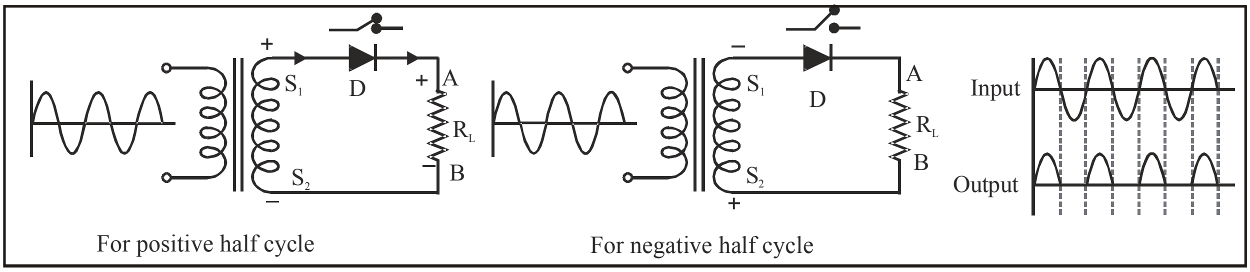
For Ideal Diode

in forward bias	in reverse bias
 $R_f = 0$	 $R_r = \infty$
'ON' switch	'OFF' switch

RECTIFIER

It is device which is used for converting alternating current into direct current.

Half wave rectifier



During the first half (positive) of the input signal, let S_1 is at positive and S_2 is at negative potential. So, the PN junction diode D is forward biased. The current flows through the load resistance R_L and output voltage is obtained.

During the second half (negative) of the input signal, S_1 and S_2 would be negative and positive respectively. The PN junction diode will be reversed biased. In this case, practically no current would flow through the load resistance. So, there will be no output voltage.

Thus, corresponding to an alternating input signal, we get a unidirectional pulsating output as shown.

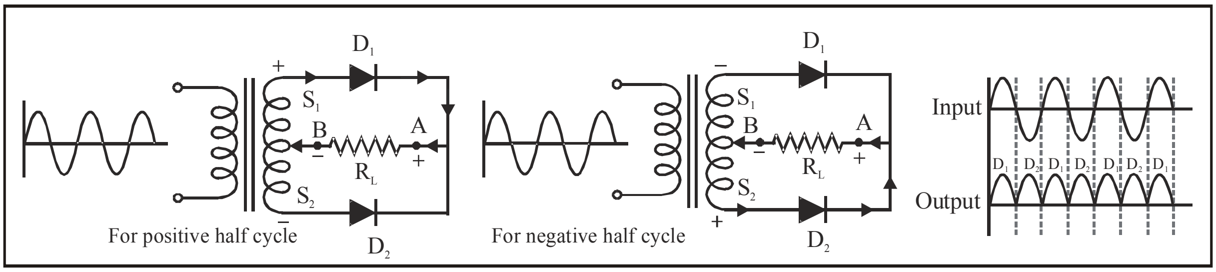
Peak inverse voltage (PIV)

In half wave rectifier PIV = maximum voltage across secondary coil of transformer (V_s)

= Peak value of output (V_m)

Full wave rectifier

When the diode rectifies the whole of the AC wave, it is called full wave rectifier. Figure shows the experiemental arrangement for using diode as full wave rectifier. The alternating signal is fed to the primary a transformer. The output signal appears across the load resistance R_L.



During the positive half of the input signal :

Let S_1 positive and S_2 negative.

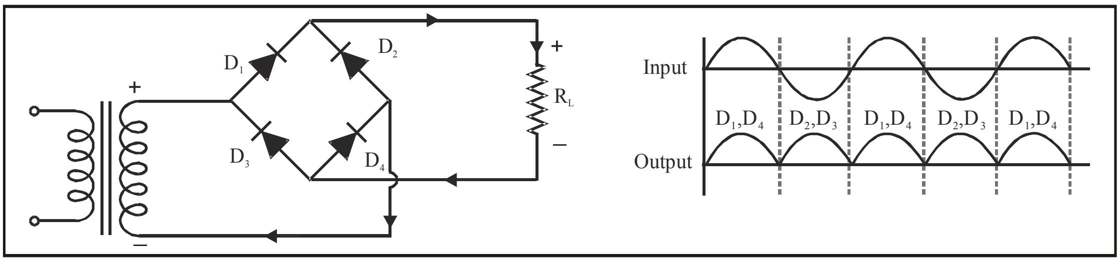
In this case diode D_1 is forward biased and D_2 is reverse biased. So only D_1 conducts and hence the flow of current in the load resistance R_L is from A to B.

During the negative half of the input signal :

Now S_1 is negative and S_2 is positive. So D_1 is reverse-biased and D_2 is forward biased. So only D_2 conducts and hence the current flows through the load resistance R_L from A to B.

It is clear that whether the input signal is positive or negative, the current always flows through the load resistance in the same direction and full wave rectification is obtained.

Bridge Rectifier



TRANSISTOR

Inventor William Bradford Shockley, John Bardeen and Walter Houser Brattain.

Transistor is a three terminal device which transfers a signal from low resistance circuit to high resistance circuit.

It is formed when a thin layer of one type of extrinsic semiconductor (P or N type) is sandwitched between two thick layers of other type of extrinsic semiconductor.

Each transistor have three terminals which are :-

(i) Emitter

(ii) Base

(iii) Collector

Emitter

It is the left most part of the transistor. It emits the majority carrier towards base. It is highly doped and medium in size.

Base

It is the middle part of transistor which is sandwitched by emitter (E) and collector (C). It is lightly doped and very thin in size.

Collector

It is right part of the transistor which collect the majority carriers emitted by emitter. It has large size and moderate doping.

There are two semiconducting PN-junctions in a transistor

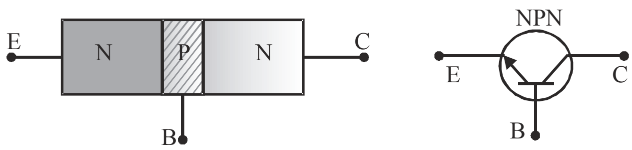
(i) The junction between emitter and base is known as emitter-base junction **(J_{EB})**.

(ii) The junction between base and collecter is known as base-collector junction **(J_{CB})**.

TRANSISTOR ARE OF TWO TYPES

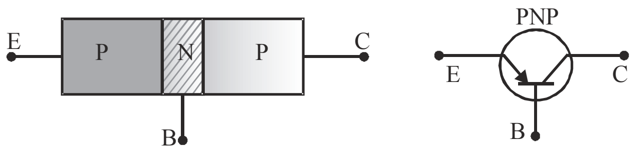
N-P-N Transistor

If a thin layer of P-type semiconductor is sandwitched between two thick layers of N-type semiconductor is known as NPN transistor.

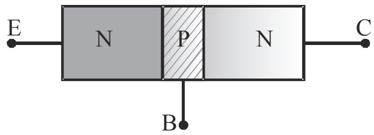


P-N-P Transistor

If a thin layer of N-type of semiconductor is sandwitched between two thick layer of P-type semiconductor is known as PNP transistor.



- Transistor have two P-N Junction J_{EB} and J_{CB}, therefore it can be biased in four following ways as given below:



Emitter-Base	Collector-Base	Region of working
Forward biased	Reverse biased	Active
Reverse biased	Forward biased	Inverse Active
Reverse biased	Reverse biased	Cut off
Forward biased	Forward biased	Saturation

- Comparsion between E, B and C

Emitter	Medium size	High dopping
Base	Smallest size	Low dopping
Collector	Largest size	Medium dopping

- The collector region is made physically larger than the emitter. Because collector has to dissipiate much greater power.

- Transistor all mostly work in active region in electronic devices & transistor work as an amplifier in Active region only.

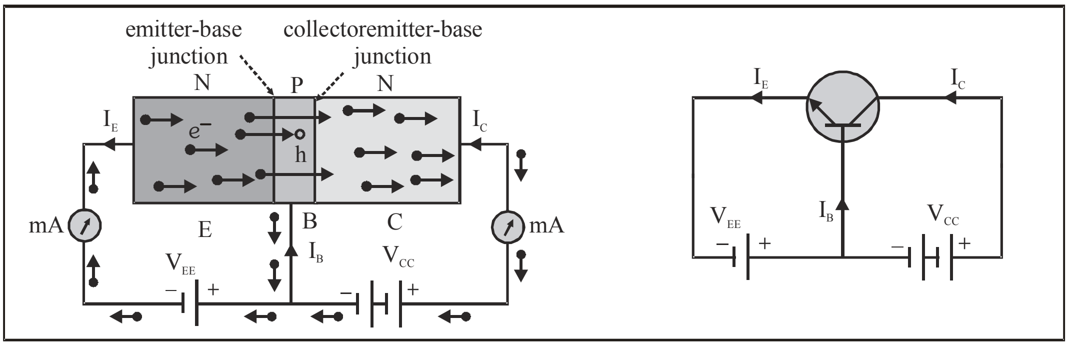
- Transistor i.e. It is a short form of two words "Transfer resistors". Signal is introduced at low resistance circuit and out put is taken at high resistance circuit.

- Base is lightly doped. Otherwise the most of the charge carrier from the emitter recombine in base region and not reaches at collector.

- Transistor is a current operated device i.e. the action of transistor is controlled by the motion of charge carriers. i.e. current.

WORKING OF NPN TRANSISTOR

The emitter Base junction is forward bias and collector base junction is reversed biased of n-p-n transistor in circuit (A) and symbolic representation is shown in Figure.



When emitter base junction is forward bias, electrons (majority carriers) in emitter are repelled toward base.

The barrier of emitter base junction is reduced and the electron enter the base, about 5% of these electron recombine with hole in base region result in small current (I_b).

The remaining electron ($\approx$95%) enter the collector region because they are attracted towards the positive terminal of battery.

For each electron entering the positive terminal of the battery is connected with collector base junction an electron from negative terminal of the battery connected with emitter base junction enters the region.

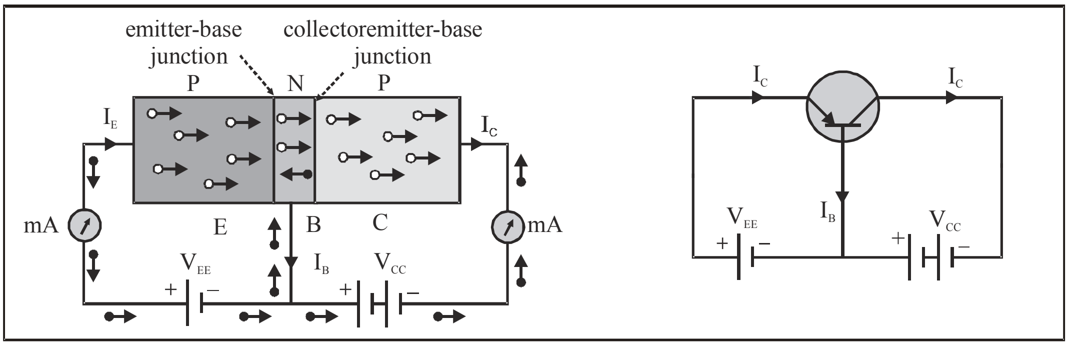
The emitter current (I_e) is more than the collector (I_c).

The base current is the difference between I_e and I_c and proportional to the number of electron hole recombination in the base.

$$I_e = I_b + I_c$$

WORKING OF PNP TRANSISTOR

When emitter-base junction is forward biased holes (majority carriers) in the emitter are repelled towards the base and diffuse through the emitter base junction. The barrier potential of emitter-base junction decreases and hole enter the n-region (i.e. base). A small number of holes ($\approx$5%) combine with electron of base-region resulting small current (I_b). The remaining hole ($\approx$95%) enter into the collector region because they are attracted towards negative terminal of the battery connected with the collector-base junction. These hole constitute the collector current (I_c).



As one hole reaches the collector, it is neutralized by the battery. As soon as one electron and a hole is neutralized in collector a covalent bond is broken in emitter region. The electron hole pair is produced. The released electron enter the positive terminal of battery and hole more towards the collector.

Basic Transistor Circuit Configurations :-

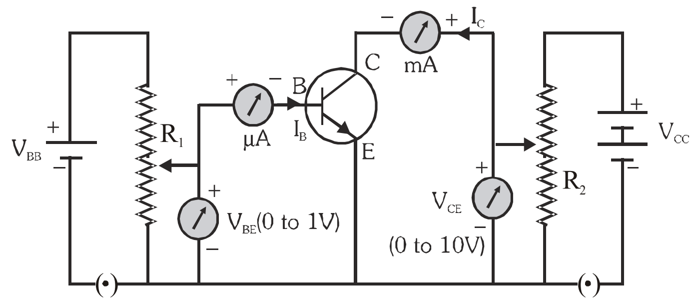
To study about the characterstics of transistor we have to make a circuit [In which four terminals are required]. But the transistor have three terminals, so one of the terminal of transistor is made common in input and output both. Thus, we have three possible configuration of transistor circuit.

(i) Common base (ii) Common emitter (iii) Common collector

In these three common emitter is widely used and common collector is rarely used.

Common emitter characterstics of a transistor

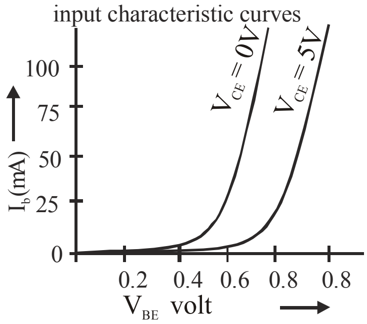
Circuit Diagram :



Circuit diagram for characteristic curve of n-p-n transistor in CE mode

Input characterstics

The variation of base current (I_b) (input) with base emitter voltage (V_{EB}) at constant-emitter voltage (V_{CE}) is called input characterstic.



(i) Keep the collector-emitter voltage (V_{CE}) constant (say V_{CE} = 1V)

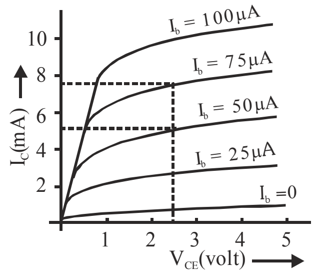
(ii) Now change emitter base voltage by R_1 and note the corresponding value of base current (I_b).

(iii) Plot the graph between V_{EB} and I_b.

(iv) A set of such curves can be plotted at different (V_{CE} = 2V)

Output characterstics

The variation of collector current I_c (output) with collector-emitter voltage (V_{CE}) at constant base current (I_b) is called output characterstic.



(i) Keep the base current (I_b) constant (say $I_b = 10\mu A$)

(ii) Now change the collector-emitter voltage (V_{CE}) using variable resistance R_2 and note the corresponding values of collector current (I_c).

(iii) Plot the graph between (V_{CE} versus I_c)

(iv) A set of such curves can be plotted at different fixed values of base current (say 0, 20 μA, 30 μA etc.)

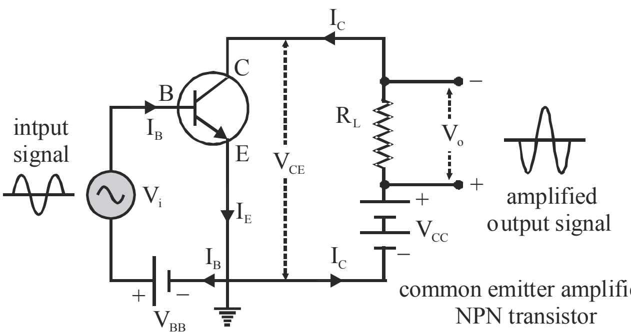
TRANSISTOR AS AN AMPLIFIER

The process of increasing the amplitude of input signal without distorting its wave shape and without changing its frequency is known as amplification.

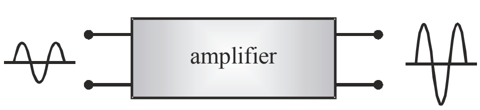
A device which increases the amplitude of the input signal is called amplifier.

A transistor can be used as an amplifier in active state.

A basic circuit of a common emitter transistor amplifier is shown.



common emitter amplifier
NPN transistor



LOGIC GATES

INTRODUCTION :

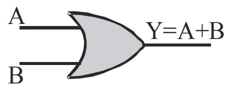
- A logic gate is a digital circuit which is based on certain logical relationship between the input and the output voltages of the circuit.
- The logic gates are built using the semiconductor diodes and transistors.
- Each logic gate is represented by its characteristic symbol.
- The operation of a logic gate is indicated in a table, known as truth table. This table contains all possible combinations of inputs and the corresponding outputs.
- A logic gate is also represented by a Boolean algebraic expression. Boolean algebra is a method of writing logical equations showing how an output depends upon the combination of inputs. Boolean algebra was invented by George Boole.

BASIC LOGIC GATES

There are three basic logic gates. They are (1) OR gate (2) AND gate, and (3) NOT gate

- **The OR gate :-** The output of an OR gate attains the state 1 if one or more inputs attain the state 1.

  Logic symbol of OR gate



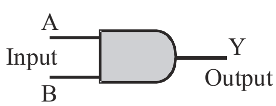
  The Boolean expression of OR gate is Y = A + B, read as Y equals A 'OR' B.

  Truth table of a two-input OR gate

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

- **The AND gate :-** The output of an AND gate attains the state 1 if and only if all the inputs are in state 1.

  Logic symbol of AND gate



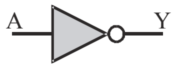
  The Boolean expression of AND gate is Y = A.B

  It is read as Y equals A 'AND' B

  Truth table of a two-input AND gate

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

- **The NOT gate :** The output of a NOT gate attains the state 1 if and only if the input does not attain the state 1.

  Logic symbol of NOT gate 

  The Boolean expression is $Y = \overline{A}$, read as Y equals NOT A.

  Truth table of NOT gate

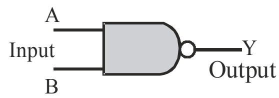
A	Y
0	1
1	0

COMBINATION OF GATES :

The three basis gates (OR, AND and NOT) when connected in various combinations give us logic gates such as NAND, NOR gates, which are the universal building blocks of digital circuits.

- **The NAND gate :**

  Logic symbol of NAND gate



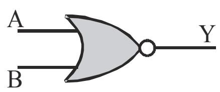
  The Boolean expression of NAND gate is $Y = \overline{A.B}$

  Truth table of a NAND gate

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

- **The NOR gate :**

  Logic symbol of NOR gate



  The Boolean expression of NOR gate is $Y = \overline{A + B}$

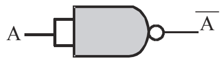
  Truth table of a NOR gate

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

UNIVERSAL GATES :

The NAND or NOR gate is the universal building block of all digital circuits. Repeated use of NAND gates (or NOR gates) gives other gates. Therefore, any digital system can be achieved entirely from NAND or NOR gates. We shall show how the repeated use of NAND (and NOR) gates will gives us different gates.

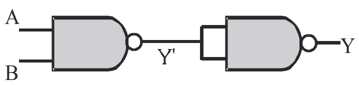
- **The NOT gate from a NAND gate :-** When all the inputs of a NAND gate are connected together, as shown in the figure, we obtain a NOT gate



Truth table of a single input NAND gate

A	B= (A)	Y
0	0	1
1	1	0

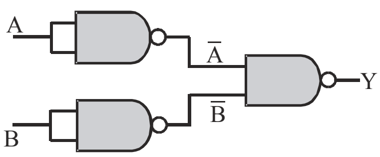
- **The AND gate from a NAND gates :-** If a NAND gate is followed by a NOT gate (i.e., a single input NAND gate), the resulting circuit is an AND gate as shown in figure and truth table given show how an AND gate has been obtained from NAND gates.



Truth table

A	B	Y'	Y
0	0	1	0
0	1	1	0
1	0	1	0
1	1	0	1

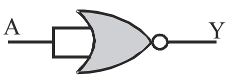
- **The OR gate from NAND gates :-** If we invert the inputs A and B and then apply them to the NAND gate, the resulting circuit is an OR gate.



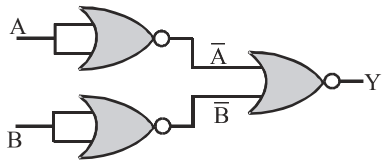
Truth table

A	B	$\overline{A}$	$\overline{B}$	Y
0	0	1	1	0
0	1	1	0	1
1	0	0	1	1
1	1	0	0	1

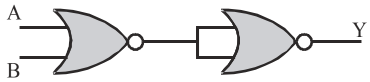
- **The NOT gate from NOR gates :-** When all the inputs of a NOR gate are connected together as shown in the figure, we obtain a NOT gate



- **The AND gate from NOR gates :-** If we invert the inputs A and B and then apply them to the NOR gate, the resulting circuit is an AND gate.



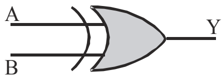
- **The OR gate from NOR gate :-** If a NOR gate is followed by a single input NOR gate (NOT gate), the resulting circuit is an OR gate.



XOR AND XNOR GATES :

- **The Exclusive - OR gate (XOR gate):-** The output of a two-input XOR gate attains the state 1 if one and only one input attains the state 1.

  Logic symbol of XOR gate



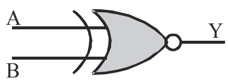
  The Boolean expression of XOR gate is $Y = A.\overline{B} + \overline{A}.B$ or $Y = A \oplus B$

  Truth table of a XOR gate

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

- **Exclusive - NOR gate (XNOR gate):-** The output is in state 1 when its both inputs are the same that is, both 0 or both 1.

  Logic symbol of XNOR gate

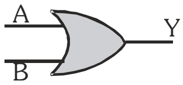
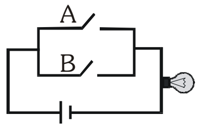
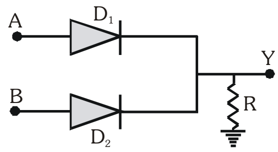
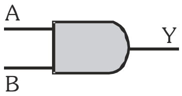
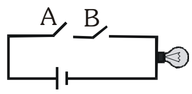
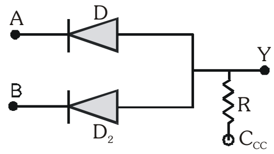
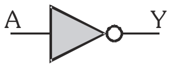
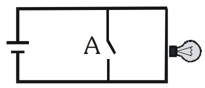
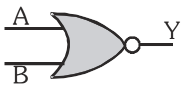
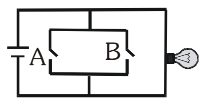
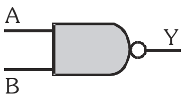
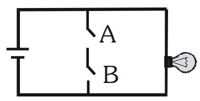
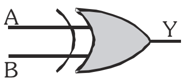
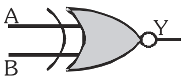


  The Boolean expression of XNOR gate is $Y = A.B + \overline{A}.\overline{B}$ or $Y = \overline{A \oplus B}$ or $A \odot B$

  Truth table of a XNOR gate

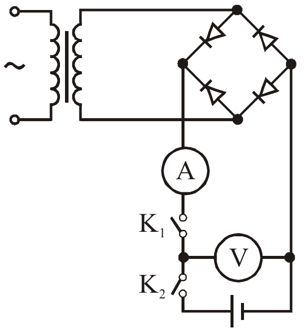
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

SUMMARY OF LOGIC GATES

Names	Symbol	Boolean Expression	Truth table	Electrical analogue	Circuit diagram (Practical Realisation)
OR		$Y = A + B$	A B Y 0 0 0 0 1 1 1 0 1 1 1 1		
AND		$Y = A.\ B$	A B Y 0 0 0 0 1 0 1 0 0 1 1 1		
NOT Inverter		$Y = \bar{A}$	A Y 0 1 1 0		
NOR (OR +NOT)		$Y = \overline{A + B}$	A B Y 0 0 1 0 1 0 1 0 0 1 1 0		
NAND (AND+NOT)		$Y = \overline{A.B}$	A B Y 0 0 1 0 1 1 1 0 1 1 1 0		
XOR (Exclusive OR)		$Y = A \oplus B$ or $Y = \bar{A}.B + A\bar{B}$	A B Y 0 0 0 0 1 1 1 0 1 1 1 0		
XNOR (Exclusive NOR)		$Y = A \odot B$ or $Y = A.B + \bar{A}.\bar{B}$ or $Y = \overline{A \oplus B}$	A B Y 0 0 1 0 1 0 1 0 0 1 1 1		

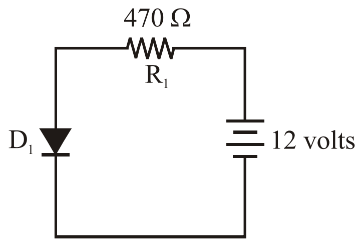
EXERCISE-S

1. The battery is charged from full wave rectifier fed by a sinusoidal voltage (see figure). Ideal diodes, ammeter and voltmeter show the time-average value. At idle with only key K_1 closed, voltmeter shows 12 V, and current is then absent, ie, reading of ammeter is 0. If only the key K_2 is closed, the voltmeter shows battery voltage at 12.3 V. During charging, when the K_2 and K_1 are closed, the voltmeter shows 12.8 V and ammeter shows 5 A. Find the internal resistance of battery.



SC0001

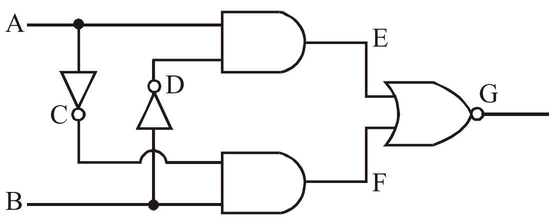
2. Complete the following table of values for this diode circuit, assuming a typical forward voltage drop of 0.65 volts for the diode:



	R_1	D_1	Total
V			12 V
I			
R	470 Ω	☒	☒
P			

SC0002

3. Write a truth table for the circuit in figure, including the states at C, D, E, F and G.



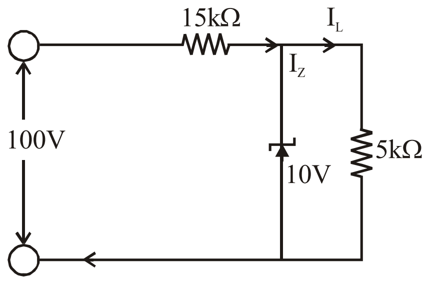
SC0003

4. For the circuit shown in figure, find

i) the output voltage

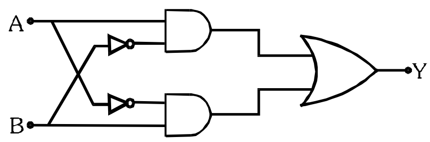
ii) the voltage drop across series resistance

iii) the current through zener diode.



SC0004

5. Write down the actual logic operation carried by the following circuit. Explain your answer.



SC0005

EXERCISE-O

SINGLE CORRECT TYPE QUESTIONS

1. An electric field is applied to a semi-conductor. Let the number of charge carriers be n and the average drift speed be v. If the temperature is increased

(A) Both n and v will increase (B) n will increase but v will decrease

(C) v will increase but n will decrease (D) Both n and v will decrease

SC0006

2. The manifestation of band structure in solids is due to - **[AIEEE-2004]**

(A) Bohr's correspondence principle (B) Pauli's exclusion principle

(C) Heisenberg's uncertainty principle (D) Boltzmann's law

SC0007

3. P-type semiconductor is formed when

A. As impurity is mixed in Si B. Al impurity is mixed in Si

C. B impurity is mixed in Ge D. P impurity is mixed in Ge

(A) A and C (B) A and D (C) B and C (D) B and D

SC0008

4. In extrinsic semiconductors -

(A) The conduction band and valence band overlap

(B) The gap between conduction band and valence band is more than 16 eV

(C) The gap between conduction band and valence band is near about 1 eV

(D) The gap between conduction band and valence band will be 100 eV and more

SC0009

5. A strip of copper and another of germanium are cooled from room temperature to 80 K. The resistance of - **[AIEEE-2004]**

(A) copper strip increases and that of germanium decreases

(B) copper strip decreases and that of germanium increases

(C) each of these increases

(D) each of these decreases

SC0010

6. In a P-N junction diode not connected to any circuit -

(A) the potential in the same everywhere

(B) the P-type side is at a higher potential then the N-type side

(C) there is an electric field at the junction directed from the N-type side to the P-type side

(D) there is an electric field at the junction directed from the P-type to the N-type side

SC0011

7. When p-n junction diode is forward biased, then. **[AIEEE-2004]**

(A) both the depletion region and barrier height are reduced

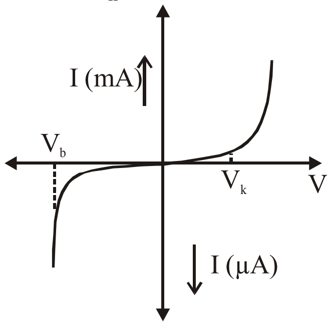
(B) the depletion region is widened and barrier height is reduced

(C) the depletion region is reduced and barrier height is increased

(D) both the depletion region and barrier height are increased

SC0012

8. The V-I characteristic for a p-n junction diode is plotted as shown in the figure. From the plot we can conclude that [$V_b \rightarrow$ breakdown voltage, $V_k \rightarrow$ knee voltage]



(A) the forward bias resistance of diode is very high; almost infinity for small values of V and after a certain value it becomes very low

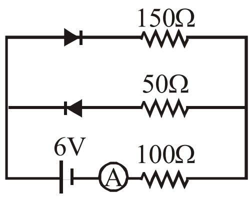
(B) the reverse bias resistance of diode is very high in the beginning upto breakdown voltage is not achieved

(C) both forward and reverse bias resistances are same for all voltages

(D) both (A) and (B) are correct

SC0013

9. In the below given arrangement determine the ammeter reading, if each diodes have a forward resistance of 50 Ω and infinite backward resistance -

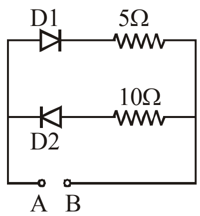


(A) zero (B) 0.02 (C) 0.03 (D) 0.036

SC0014

10. A 2V battery is connected across AB as shown in the figure. The value of the current supplied by the battery when in one case battery's positive terminal is connected to A and in other case when positive terminal of battery is connected to B will respectively be :-

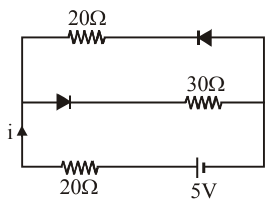
(JEE-Main Online-2015)



(A) 0.1 A and 0.2 A (B) 0.4 A and 0.2 A (C) 0.2 A and 0.4 A (D) 0.2 A and 0.1 A

SC0015

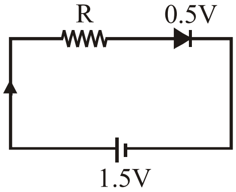
11. Current in the circuit will be -



(A) $\frac{5}{40}$ A (B) $\frac{1}{10}$ A (C) $\frac{5}{10}$ A (D) $\frac{5}{20}$ A

SC0016

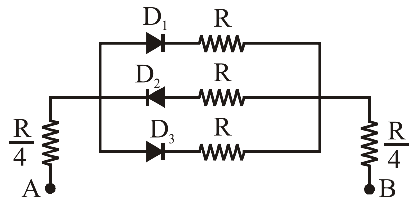
12. The diode used in the circuit shown in the figure has a constant voltage drop of 0.5 V at all currents and a maximum power rating of 100 milliwatts. What should be the value of the resistor R connected in series with the diode for obtaining maximum current -



(A) 1.5 Ω (B) 5 Ω (C) 6.67 Ω (D) 200 Ω

SC0017

13. In the following circuits PN-junction diodes D_1, D_2 and D_3 are ideal for the following potential of A and B, the correct increasing order of resistance between A and B will be -

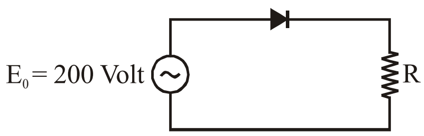


(i) –10V, –5V, (ii) –5V, –10V (iii) –4V, –12V

(A) (i) < (ii) < (iii) (B) (iii) < (ii) < (i) (C) (ii) = (iii) < (i) (D) (i) = (iii) < (ii)

SC0018

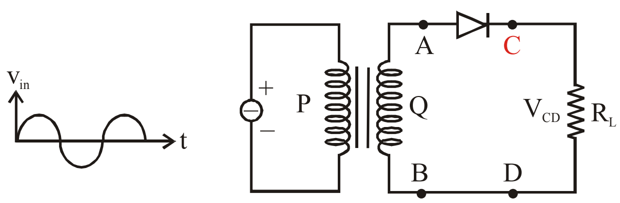
14. A sinusoidal voltage of peak value 200 volt is connected to a diode and resistor R in the circuit shown so that half wave rectification occurs. If the forward resistance of the diode is negligible compared to R then rms voltage (in volt) across R is approximately -

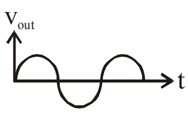
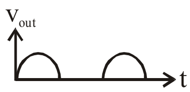
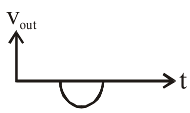
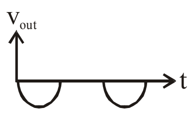


(A) 200 (B) 100 (C) $\frac{200}{\sqrt{2}}$ (D) 280

SC0019

15. In the half-wave rectifier circuit shown. Which one of the following wave forms is true for V_{CD}, if the input is as shown?



(A)  (B)  (C)  (D) 

SC0020

16. Zener diode is a p-n junction which has -

(A) p-end heavily doped, n-end lightly doped

(B) n-end heavily doped, p-end lightly doped

(C) both p and n-ends heavily doped

(D) both p and n-ends lightly doped

SC0021

17. Zener diode has both p and n-ends heavily doped so that -

(A) it has small thickness of depletion region

(B) it has large thickness of depletion region due to large recombination

(C) it has large reverse bias voltage

(D) it has weak reverse current when reverse biased

SC0022

18. Most important use of zener diode is to have –

(A) constant voltage across applied load

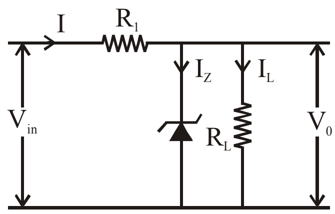
(B) any desired current at constant voltage

(C) a p-n junction working under constant regulated voltage conditions

(D) a p-n junction to operate at high voltages

SC0023

19. In given figure when input voltage increases,



(A) the current through R_S, R_L and zener increases

(B) the current through R_S increases, zener increases but through R_L remains constant

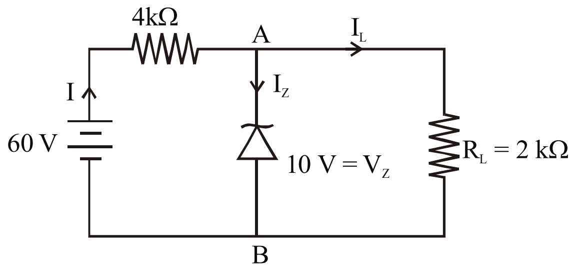
(C) the current through R_S increases, through zener decreases, R_L increases

(D) the current through R_S increases, through zener remains constant but R_L increases

SC0024

20. A Zener diode is connected to a battery and a load as shown below. The currents I, I_Z and I_L are respectively.

(JEE-Main Online-2014)



(A) 12.5 mA, 5 mA, 7.5 mA

(B) 15 mA, 7.5 mA, 7.5 mA

(C) 12.5 mA, 7.5 mA, 5 mA

(D) 15 mA, 5 mA, 10 mA

SC0025

21. A transistor is used in common emitter mode as an amplifier, then:
(1) the base emitter junction is forward biased
(2) the base emitter junction is reverse biased
(3) the input signal is connected in series with the voltage applied to bias the base emitter junction
(4) the Input signal is connected is series with the voltage applied to bias the base collector junction which is correct-
(A) 1, 2, 3 (B) 1, 2, 3, 4 (C) 1, 3 (D) 2, 3, 4

SC0026

22. In a n-p-n transistor circuit the collector current is 10 mA. If 90% of the electron emitted reach the collector then -
(A) the emitter current will be 9 mA (B) the base current will be 9 mA
(C) the emitter current will be 11 mA (D) the base current will be -1 mA

SC0027

23. n-p-n transistors are preferred to p-n-p transistors because -
(A) they have low cost
(B) they have low dissipation energy
(C) they are capable of handling large power
(D) electrons have high mobility than holes.

SC0028

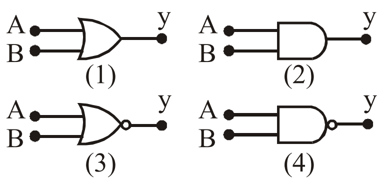
24. When npn transistor is used as an amplifier **[AIEEE-2004]**
(A) electrons move from collector to base
(B) holes move from emitter to base .
(C) electrons move from base to collector
(D) holes move from base to emitter

SC0029

25. For a transistor, α is 0.8. The transistor is in CE configuration. The change in the collector current when the base current changes by 6 mA is :-
(A) 6 mA (B) 4.8mA (C) 24mA (D) 8mA

SC0030

26. Given below are four logic gate symbol (figure). Those for OR, NOR and NAND are respectively



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

SC0031

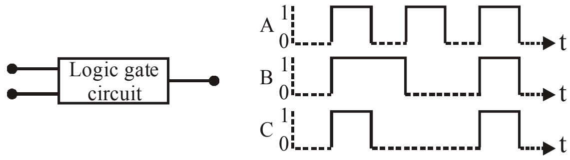
27. The following truth table corresponds to the logic gate -

A	0	0	1	1
B	0	1	0	1
X	0	1	1	1

(A) NAND (B) OR (C) AND (D) XOR

SC0032

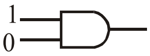
28. The following figure shows a logic gate circuit with two input A and B output C. The voltage waveforms of A, B and C are as shown in second figure below. The logic gate is :

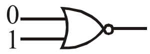


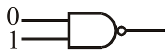
(A) OR gate (C) NAND gate (B) AND gate (D) NOR gate

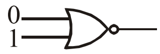
SC0033

29. Which of the following gates will have an output of 1 -

(A) 

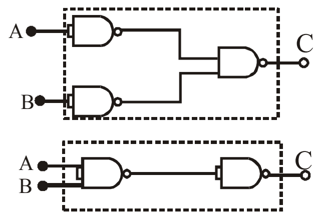
(B) 

(C) 

(D) 

SC0034

30. The combination of 'NAND' gates shown here under (figure) are equivalent to -



(A) An OR gate and an AND gate respectively

(B) An AND gate and a NOT gate respectively

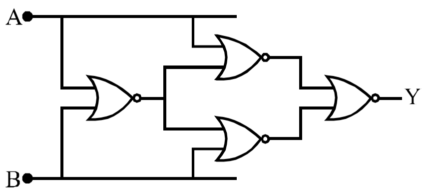
(C) An AND gate and an OR gate respectively

(D) An OR gate and a NOT gate respectively

SC0035

31. A system of four gates is set up as shown.The 'truth table' corresponding to this system is :-

(JEE-Main Online-2013)



(A)

A	B	Y
0	0	0
0	1	0
1	0	1
1	1	1

(B)

A	B	Y
0	0	1
0	1	1
1	0	0
1	1	0

(C)

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

(D)

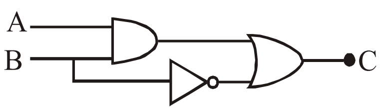
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

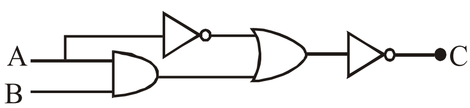
SC0036

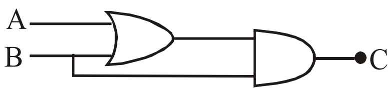
32. Which of the following circuits correctly represents the following truth table ?

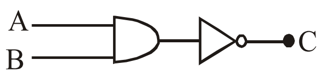
(JEE-Main Online-2013)

A	B	C
0	0	0
0	1	0
1	0	1
1	1	0

(A) 

(B) 

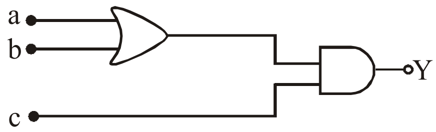
(C) 

(D) 

SC0037

33. To get an output of 1 from the circuit shown in figure the input must be :-

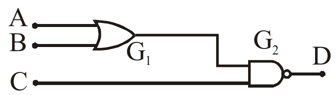
(JEE-Main Online-2016)



(A) a = 1, b = 0, c = 1 (B) a = 1, b = 0, c = 0
(C) a = 0, b = 1, c = 0 (D) a = 0, b = 0, c = 1

SC0038

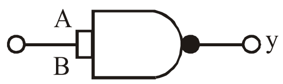
34. For the given combination of gates, if the logic states of inputs A, B, C are as follows A = B = C = 0 and A = B = 1, C = 0 then the logic states of output D are -



(A) 0, 0 (B) 0, 1 (C) 1, 0 (D) 1,1

SC0039

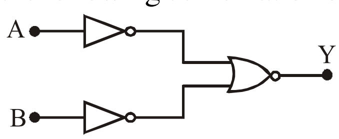
35. This symbol represents



(A) NOT gate (B) OR (C) AND gate (D) NOR gate

SC0040

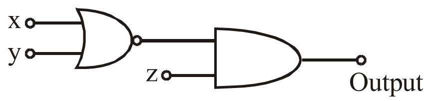
36. Which logic gate is represented by the following combination of logic gates -



(A) OR (B) NAND (C) AND (D) NOR

SC0041

37. In which of the following cases, we would obtain an output of one.



(A) x = l, y = l, z = l (B) x = l, y = l, z = 0 (C) x = 0, y = l, z = l (D) x = 0, y = 0, z = l

SC0042

38. In a full wave rectifier circuit operating from 50 Hz mains frequency, the fundamental frequency in the ripple would be :- **[AIEEE-2005]**

(A) 50 Hz (B) 25Hz (C) 100 Hz (D) 70.7 Hz

SC0043

39. The electrical conductivity of a semiconductor increases when electromagnetic radiation of wavelength shorter than 2480 nm is incident on it. The band gap (in eV) for the semiconductor is

[AIEEE-2005]

(A) 1.1 eV (B) 2.5 eV (C) 0.5 eV (D) 0.7 eV

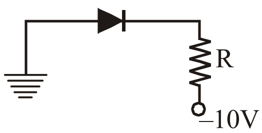
SC0044

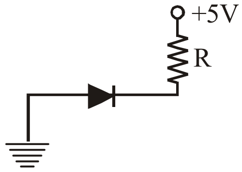
40. If the ratio of the concentration of electrons to that of holes in a semiconductor is $\frac{7}{5}$ and the ratio of currents is $\frac{7}{4}$ then what is the ratio of their drift velocities - **[AIEEE-2006]**

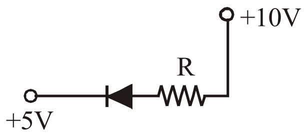
(A) $\frac{5}{4}$ (B) $\frac{4}{7}$ (C) $\frac{5}{6}$ (D) $\frac{4}{5}$

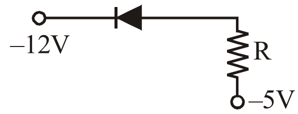
SC0045

41. In the following, which one of the diodes is reverse biased ; **[AIEEE-2006]**

(A) 

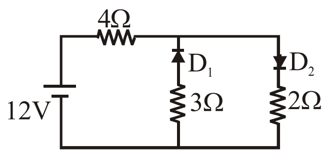
(B) 

(C) 

(D) 

SC0046

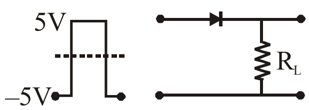
42. The circuit has two oppositely connected ideal diodes in parallel. What is the current flowing in the circuit ? **[AIEEE-2006]**

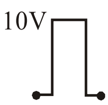


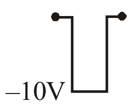
(A) 2.31 A (B) 1.33 A (C) 1.71 A (D) 2.00 A

SC0047

43. If in a p-n junction diode, a square input signal of 10V is applied as shown. Then the output signal across R_L will be :- **[AIEEE-2007]**



(A) 

(B) 

(C) 

(D) 

SC0048

44. Carbon, silicon and germanium have four valence electrons each. At room temperature which one of the following statements is most appropriate ? **[AIEEE-2007]**

(A) The number of free conduction electrons is significant in C but small in Si and Ge

(B) The number of free conduction electrons is negligibly small in all the three

(C) The number of free electrons for conduction is significant in all the three

(D) The number of free electrons for conduction is significant only in Si and Ge but small in C

SC0049

MULTIPLE CORRECT TYPE QUESTIONS

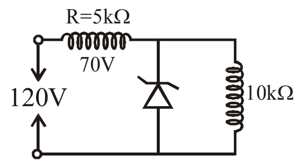
45. Which of the following statements is correct
(A) Resistance of semiconductor decreases with increase in temperature
(B) In an electric field, displacement of holes is opposite to the displacement of electrons
(C) Resistance of a conductor decreases with the increase in temperature
(D) n-type semiconductors are neutral

SC0050

46. Pick out the correct statement the reverse current in p-n junction diode
(A) can be minimum and constant
(B) remains constant even after the breakdown voltage
(C) becomes infinity at breakdown
(D) reverse current is controlled by external resistance

SC0051

47. For the circuit shown in the figure:



(A) current through zener diode is 4 mA
(B) current through zener diode is 9 mA
(C) the output voltage is 50 V
(D) the output voltage is 40 V

SC0052

48. Which of the following devices are heavily doped p-n junction
(A) Photo diode
(B) Light emitting diode
(C) Solar cell
(D) Zener mode

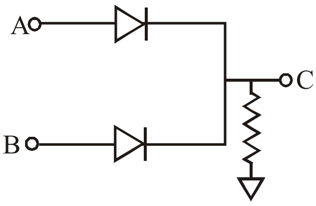
SC0053

49. Which of the following statements is correct for proper working of zener diode ?
(A) Reverse bias voltage should be less than or equal to zener breakdown voltage
(B) Reverse bias voltage applied must be greater than zener breakdown voltage.
(C) Zener is to be reverse biased for zener action
(D) For given zener diode there can be different zener breakdown voltages

SC0054

EXERCISE-JM

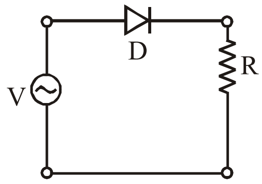
1. In the circuit below, A and B represent two inputs and C represents the output. **[AIEEE-2008]**



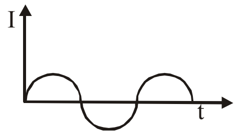
The circuit represents
(1) AND gate (2) NAND gate (3) OR gate (4) NOR gate

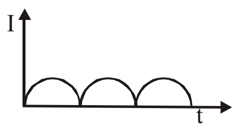
SC0055

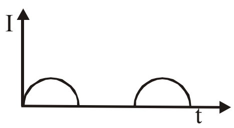
2. An p-n junction (D) shown in the figure can act as a rectifier. An alternating current source (V) is connected in the circuit.

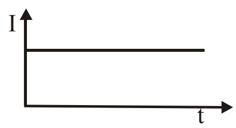


The current (I) in the resistor R can be shown by: **[AIEEE-2009]**

(1) 

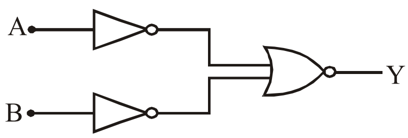
(2) 

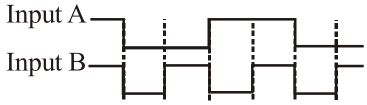
(3) 

(4) 

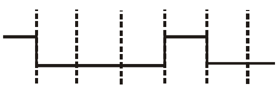
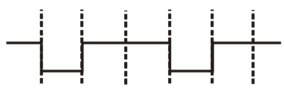
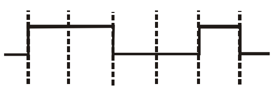
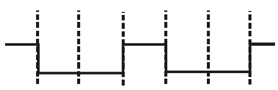
SC0056

3. The logic circuit shown below has the input wave forms 'A' and 'B' as shown. Pick out the correct output waveform. **[AIEEE-2009]**



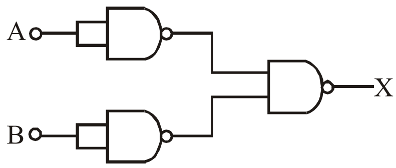


Output is -

(1) 
(2) 
(3) 
(4) 

SC0057

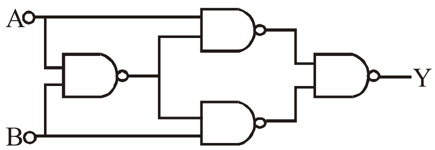
4. The combination of gates shown below yields. **[AIEEE-2010]**



(1) XOR gate (2) NAND gate (3) OR gate (4) NOT gate

SC0058

5. Truth table for system of four NAND gates as shown in figure is: **[AIEEE-2012]**



(1)

A	B	Y
0	0	1
0	1	1
1	0	0
1	1	0

(2)

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

(3)

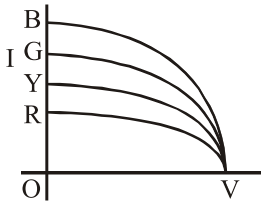
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

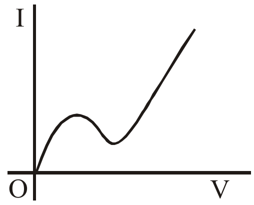
(4)

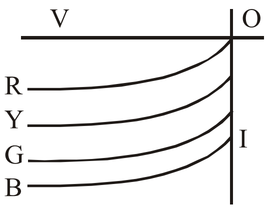
A	B	Y
0	0	0
0	1	0
1	0	1
1	1	1

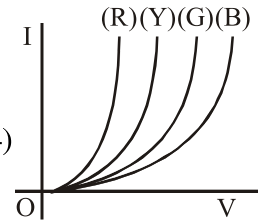
SC0059

6. The I-V characteristic of an LED is **[JEE Main 2013]**

(1) 

(2) 

(3) 

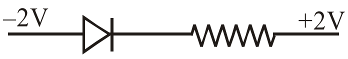
(4) 

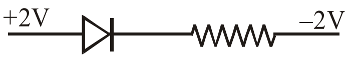
SC0060

7. The forward biased diode connection is: **[JEE Main-2014]**

(1) 

(2) 

(3) 

(4) 

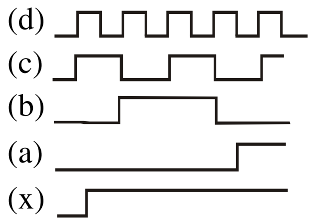
SC0061

8. For a common emitter configuration, if α and β have their usual meanings, the **incorrect** relationship between α and β is **[JEE Main-2016]**

(1) $\alpha = \frac{\beta^2}{1+\beta^2}$ (2) $\frac{1}{\alpha} = \frac{1}{\beta} + 1$ (3) $\alpha = \frac{\beta}{1-\beta}$ (4) $\alpha = \frac{\beta}{1+\beta}$

SC0062

9. If a, b, c, d are inputs to a gate and x is its output, then as per the following time graph, the gate is **[JEE Main-2016]**



(1) NAND (2) NOT (3) AND (4) OR

SC0063

10. The temperature dependence of resistances of Cu and undoped Si in the temperature range 300-400K, is best described by :- **[JEE Main-2016]**

(1) Linear decrease for Cu, linear decrease for Si.

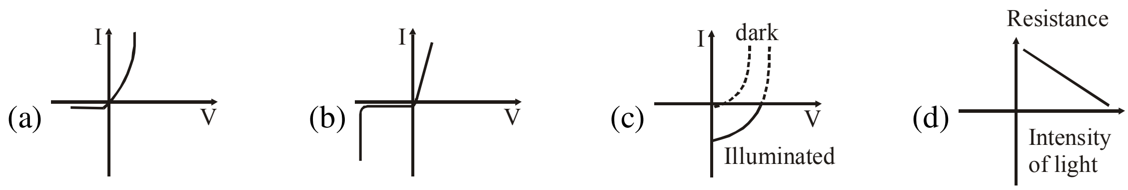
(2) Linear increase for Cu, linear increase for Si.

(3) Linear increase for Cu, exponential increase for Si

(4) Linear increase for Cu, exponential decrease for Si

SC0064

11. Identify the semiconductor devices whose characteristics are given below, in the order (a), (b), (c), (d):- **[JEE Main-2016]**



(1) Zener diode, Solar cell, Simple diode, Light dependent resistance

(2) Simple diode, Zener diode, Solar cell, Light dependent resistance

(3) Zener diode, Simple diode, Light dependent resistance, Solar cell

(4) Solar cell, Light dependent resistance, Zener diode, Simple diode

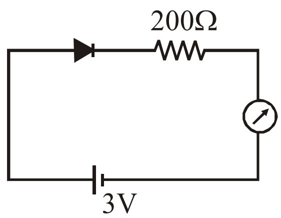
SC0065

12. In a common emitter amplifier circuit using an n-p-n transistor, the phase difference between the input and the output voltages will be : **[JEE Main-2017]**

(1) 135° (2) 180° (3) 45° (4) 90°

SC0066

13. The reading of the ammeter for a silicon diode in the given circuit is :- **[JEE Main-2018]**

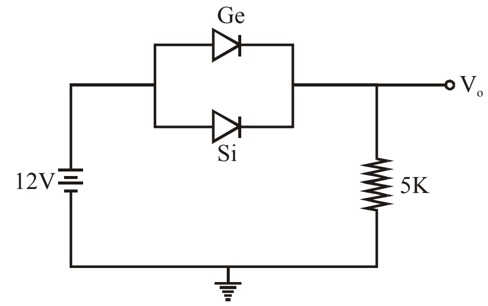


(1) 15 mA (2) 11.5 mA (3) 13.5 mA (4) 0

SC0067

SELECTED PROBLEMS FROM JEE-MAINS ONLINE PAPERS

14. Ge and Si diodes start conducting at 0.3 V and 0.7 V respectively. In the following figure if Ge diode connection are reversed, the value of V_o changes by : (assume that the Ge diode has large breakdown voltage) **[JEE Main-2019_Jan]**



(1) 0.6 V (2) 0.8 V (3) 0.4 V (4) 0.2 V

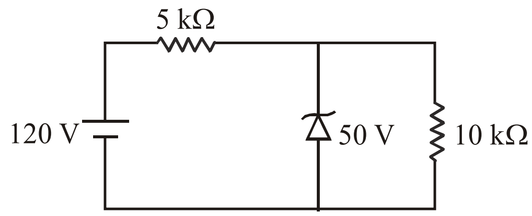
SC0068

15. Mobility of electrons in a semiconductor is defined as the ratio of their drift velocity to the applied electric field. If, for an n-type semiconductor, the density of electrons is $10^{19} m^{-3}$ and their mobility is $1.6\ m^2/(V.s)$ then the resistivity of the semiconductor (since it is an n-type semiconductor contribution of holes is ignored) is close to: **[JEE Main-2019_Jan]**

(1) $2\Omega m$ (2) $0.4\Omega m$ (3) $4\Omega m$ (4) $0.2\Omega m$

SC0069

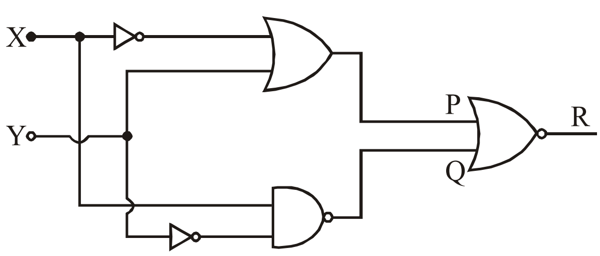
16. For the circuit shown below, the current through the Zener diode is : **[JEE Main-2019_Jan]**



(1) 5 mA (2) Zero (3) 14 mA (4) 9 mA

SC0070

17. To get output '1' at R, for the given logic gate circuit the input values must be : **[JEE Main-2019_Jan]**

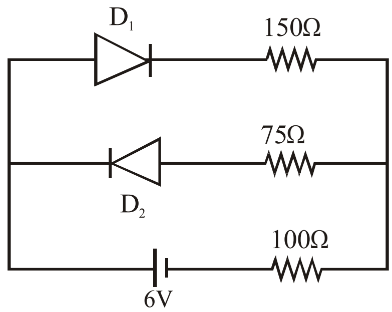


(1) X = 0, Y = 1 (2) X =1 , Y = 1 (3) X = 0, Y = 0 (4) X = 1, Y = 0

SC0071

18. The circuit shown below contains two ideal diodes, each with a forward resistance of 50Ω. If the battery voltage is 6 V, the current through the 100 Ω resistance (in Amperes) is :-

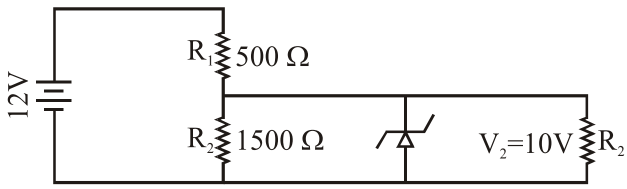
[JEE Main-2019_Jan]



(1) 0.027 (2) 0.020 (3) 0.030 (4) 0.036

SC0072

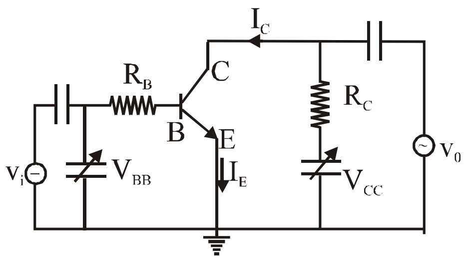
19. In the given circuit the current through Zener Diode is close to : **[JEE Main-2019_Jan]**



(1) 6.0 mA (2) 4.0 mA (3) 6.7 mA (4) 0.0 mA

SC0073

20.

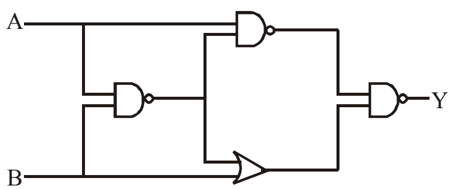


In the figure, given that V_{BB} supply can vary from 0 to 5.0 V, V_{CC} = 5V, β_{dc} = 200, R_B = 100 kΩ, R_C=1 kΩ and V_{BE}=1.0 V, The minimum base current and the input voltage at which the transistor will go to saturation, will be, respectively : **[JEE Main-2019_Jan]**

(1) 20μA and 3.5V (2) 25μA and 3.5V (3) 25μA and 2.8V (4) 20μA and 2.8V

SC0074

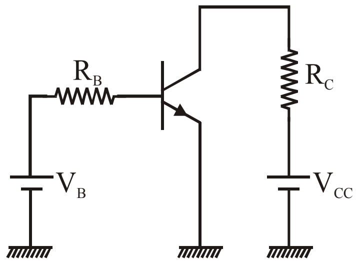
21. The output of the given logic circuit is : **[JEE Main-2019_Jan]**



(1) $\bar{A}B$ (2) $A\bar{B}$ (3) $AB+\overline{AB}$ (4) $A\bar{B}+\bar{A}B$

SC0075

22. A common emitter amplifier circuit, built using an npn transistor, is shown in the figure. Its dc current gain is 250, R_C = 1kΩ and V_{CC} = 10 V. What is the minimum base current for V_{CE} to reach saturation ? **[JEE Main-2019_April]**



(1) 100 μA (2) 7 μA (3) 40 μA (4) 10 μA

SC0076

23. An NPN transistor is used in common emitter configuration as an amplifier with 1 kΩ load resistance. Signal voltage of 10 mV is applied across the base-emitter. This produces a 3 mA change in the collector current and 15μA change in the base current of the amplifier. The input resistance and voltage gain are :

[JEE Main-2019_April]

(1) 0.33 kΩ, 1.5 (2) 0.67 kΩ, 200 (3) 0.33 kΩ, 300 (4) 0.67 kΩ, 300

SC0077

24. An npn transistor operates as a common emitter amplifier, with a power gain of 60 dB. The input circuit resistance is 100Ω and the output load resistance is 10 kΩ. The common emitter current gain β is :

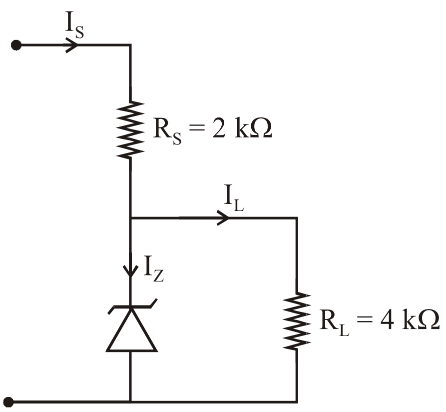
[JEE Main-2019_April]

(1) 60 (2) 10^4 (3) 6×10^2 (4) 10^2

SC0078

25. Figure shown a DC voltage regulator circuit, with a Zener diode of breakdown voltage = 6V. If the unregulated input voltage varies between 10 V to 16 V, then what is the maximum Zener current ?

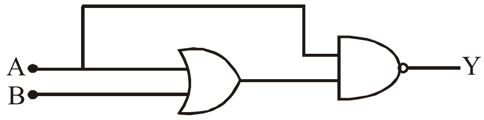
[JEE Main-2019_April]



(1) 2.5 mA (2) 3.5 mA (3) 7.5 mA (4) 1.5 mA

SC0079

26. The truth table for the circuit given in the fig. is: **[JEE Main-2019_April]**



(1)

A	B	Y
0	0	1
0	1	1
1	0	0
1	1	0

(2)

A	B	Y
0	0	0
0	1	0
1	0	1
1	1	1

(3)

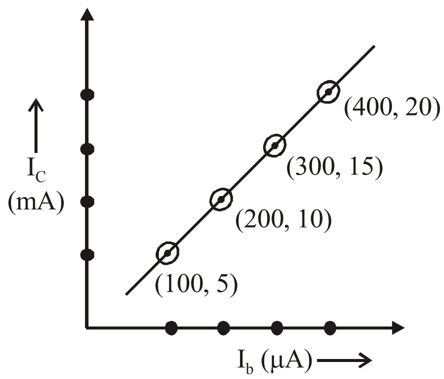
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

(4)

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	1

SC0080

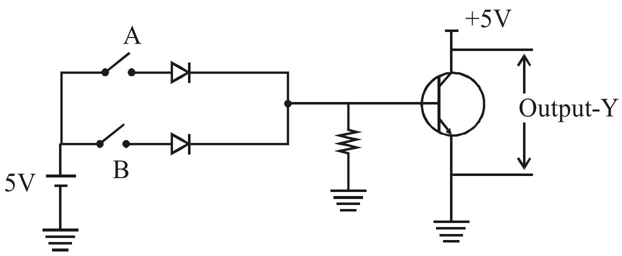
27. The transfer characteristic curve of a transistor, having input and output resistance 100 Ω and 100 kΩ respectively, is shown in the figure. The Voltage and Power gain, are respectively : **[JEE Main-2019_April]**



(1) 5×10^4, 5×10^5 (2) 5×10^4, 5×10^6 (3) 5×10^4, 2.5×10^6 (4) 2.5×10^4, 2.5×10^6

SC0081

28. Boolean relation at the output stage-Y for the following circuit is : **[JEE Main-2020_Jan]**

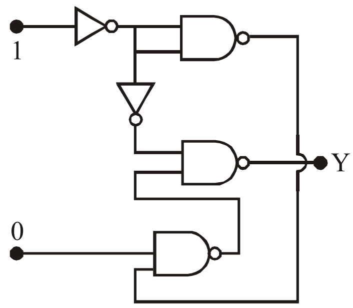


(1) $A + B$ (2) $\overline{A} + \overline{B}$ (3) $\overline{A} \cdot \overline{B}$ (4) $A \cdot B$

SC0082

node06\B0BA-BB\Kota\JEE(Advanced)\ENTHUSE\Phy\Module\Modern Physics-1-Modern Physics-2-EM & INS.-Semiconductor-PCS\Eng\4-Semiconductor\01_Theory+Ex.p65

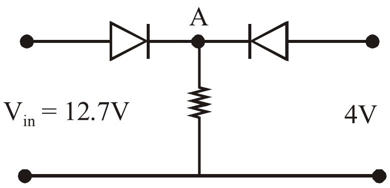
29. In the given circuit, value of Y is : **[JEE Main-2020_Jan]**



(1) will not execute (2) 0 (3) toggles between 0 and 1 (4) 1

SC0083

30. Both the diodes used in the circuit shown are assumed to be ideal and have negligible resistance when these are forward biased. Built in potential in each diode is 0.7 V. For the input voltages shown in the figure, the voltage (in Volts) at point A is __________ . **[JEE Main-2020_Jan]**



SC0084

31. If a semiconductor photodiode can detect a photon with a maximum wavelength of 400 nm, then its band gap energy is: **[JEE Main-2020_SEP]**

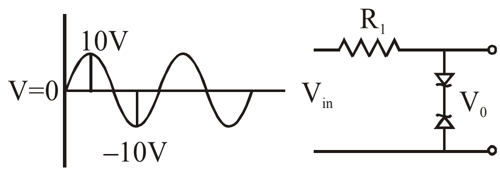
Planck's constant $h = 6.63 \times 10^{-34}$ J.s.

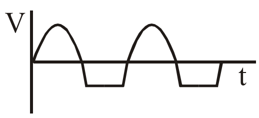
Speed of ligh $c = 3 \times 10^{8}$ m/s

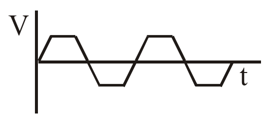
(1) 2.0 eV (2) 1.5 eV (3) 3.1 eV (4) 1.1 eV

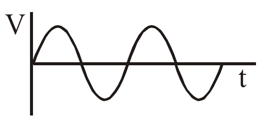
SC0085

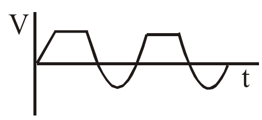
32. Take the breakdown voltage of the zener diode used in the given circuit as 6V. For the input voltage shown in figure below, the time variation of the output voltage is : (Graphs drawn are schematic and not to scale) **[JEE Main-2020_SEP]**



(1)


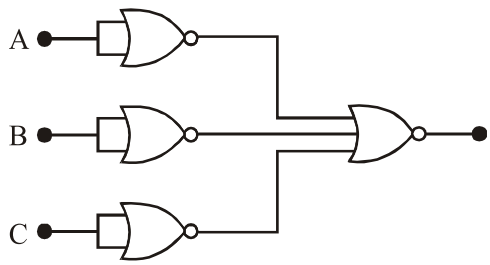
(2)


(3)


(4)


SC0086

33. Identify the operation performed by the circuit given below : **[JEE Main-2020_SEP]**



(1) AND (2) NAND (3) OR (4) NOT

SC0087

34. With increasing biasing voltage of a photodiode, the photocurrent magnitude : **[JEE Main-2020_SEP]**

(1) increases initially and saturates finally

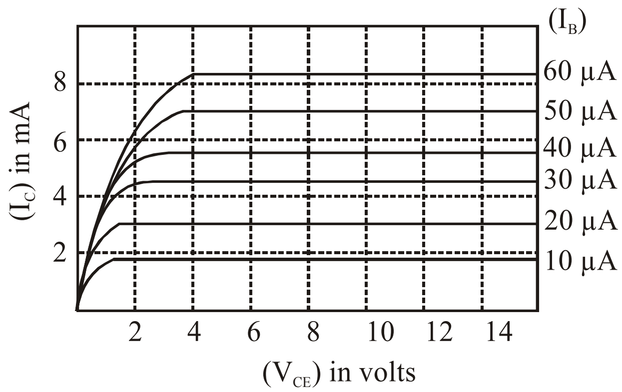
(2) increases initially and after attaining certain value, it decreases

(3) increases linearly

(4) remains constant

SC0088

35. The output characteristics of a transistor is shown in the figure. When V_{CE} is 10 V and $1_C = 4.0$ mA, then value of β_{ac} is ________ . **[JEE Main-2020_SEP]**



SC0089

CBSE Previous Year's Questions

1. Draw the voltage current characteristic of a zener diode. **[1; CBSE-2004]**

2. With the help of a labelled circuit diagram, explain how an n-p-n transistor can be used as an amplifier in common-emitter configuration. Explain how the input and output voltages are out of phase by 180° for a common-emitter transistor amplifier. **[5; CBSE-2004]**

3. How does the resistivity of (i) a conductor and (ii) a semiconductor vary with temperature? Give reason for each case. **[2; CBSE-2005]**

4. On the basis of the energy band diagrams. Distinguish between metals, insulators and semiconductors. **[3; CBSE-2005]**

5. (a) With the help of a circuit diagram explain the working of transistor as oscillator.

(b) Draw a circuit diagram for a two input OR gate and explain its working with the help of input, output waveforms. **[5; CBSE-2005]**

6. (a) Explain briefly with the help of a circuit diagram, how V -1 characteristics of a p-n junction diode are obtained in (i) forward bias, and (ii) reverse bias.

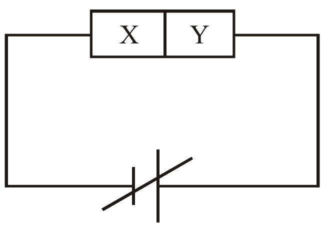
(b) A photodiode is fabricated from a semiconductor with a band gap of 2.8 eV. Can it detect wave length of 6000 nm? Justify. **[5; CBSE-2005]**

7. Explain (i) forward biasing, (ii) reverse biasing of a P-N junction diode. With the help of a circuit diagram, explain the use of this device as a half - wave rectifier. **[3; CBSE-2006]**

8. What are energy bands? How are these formed? Distinguish between a conductor, an insulator and a semiconductor on the basis of energy band diagram. **[5; CBSE-2006]**

9. Explain the function of base region of a transistor. Why is this region made thin and lightly doped? Draw a circuit diagram to study the input and output characteristics of n-p-n transistor in a common emitter (CE) configuration. Show these characteristics graphically. Explain how current amplification factor of the transistor is calculated using output characteristics. **[5; CBSE-2006]**

10. Two semiconductor materials X and Y shown in the given figure, are made by doping germanium crystal with indum and arsenic respectively. The two are joined end to end and connected to a battery as shown. **[2; CBSE-2007]**



(i) Will the junction be forward biased or reverse biased ?

(ii) Sketch a V-I graph for this arrangement.

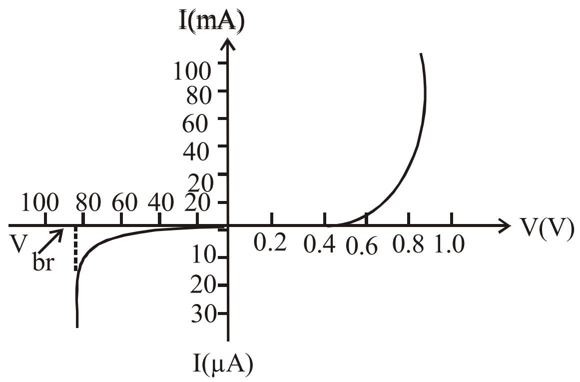
11. Draw the circuit diagram of a common emitter amplifier using n-p-n transistor. What is the phase difference between the input signal and output voltage ? State two reasons why a common emitter amplifier is preferred to a common base amplifier. **[3; CBSE-2007]**

12. Explain the formation of energy band in solids. Draw energy band diagram for (i) a conductor, (ii) an intrinsic semiconductor. **[3; CBSE-2007]**

13. Write the acronym LASER in expanded form. State any four reasons for preferring diode lasers as light sources for optical communication links. **[3; CBSE-2007]**

14. Distinguish between an intrinsic semiconductor and P-type semiconductor. Give reason, why, a P-type semiconductor crystal is electrically neutral, although $n_h >> n_e$? **[2; CBSE-2008]**

15. The figure below shows the V-I characteristic of a semiconductor diode.

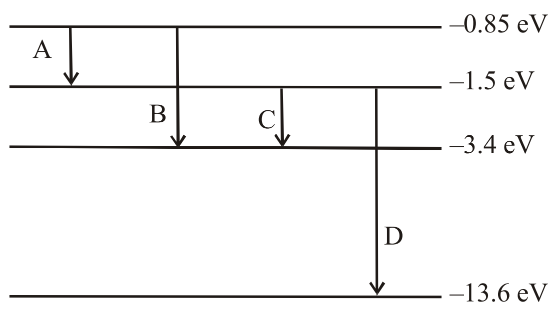


(i) Identify the semiconductor diode used.

(ii) Draw the circuit diagram to obtain the given characteristic of this device.

(iii) Briefly explain how this diode can be used as a voltage regulator. **[3; CBSE-2008]**

16. The energy level diagram of an element is given below. Identify, by doing necessary calculations, which transition corresponds to emission of a spectral line of wavelength 102.7 nm.



[3; CBSE-2008]

17. (i) Draw a circuit diagram to study the input and output characteristics of an n-p-n transistor in its common emitter configuration. Draw the typical input and output characteristics.

(ii) Explain, with the help of a circuit diagram, the working of n -p-n transistor as a common emitter amplifier. **[5; CBSE-2009]**

18. How is a zener diode fabricated so as to make it a special purpose diode? Draw I -V characteristics of zener diode and explain the significance of break down voltage. Explain briefly, with the help of a circuit diagram, how a-p-n junction diode work **[5; CBSE-2009]**

19. (a) Draw the circuit diagram of a p-n junction diode in (i) forward bias, (ii) reverse bias. How are these circuits used to study the V-I characteristics of a silicon diode ? Draw the typical V-I characteristics.

(b) What is a light emitting diode (LED)? Mention two important advantages of LEDs over conventional lamps. **[5; CBSE-2010]**

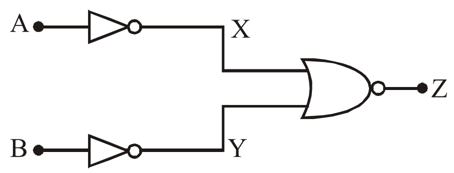
20. (a) Draw the circuit arrangement for studying the input and output characteristics of an n-p-n transistor in CE configuration. With the help of these characteristics define (i) input resistance, (ii) current amplification factor.

(b) Describe briefly with the help of a circuit diagram how an n-p-n transistor is used to produce self-sustained oscillations. **[5; CBSE-2010]**

21. What happens to the width of depletion layer of a p-n junction when it is (i) forward biased, (ii) reverse biased? **[1; CBSE-2011]**

22. Draw a labelled diagram of a full wave rectifier circuit. State its working principle. Show the input-output waveforms. **[3; CBSE-2011]**

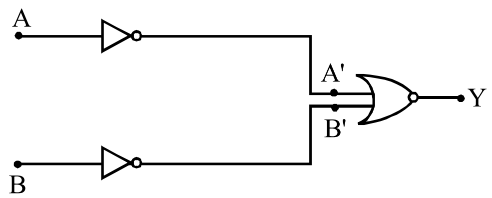
23. You are given a circuit below. Write its truth table, hence, identify the logic operation carried out by this circuit. Draw the logic symbol of the gate it corresponds to. **[3; CBSE-2011]**



24. Describe briefly with the help of a circuit diagram, how the flow of current carries in a p-n-p transistor is regulated with emitter-base junction forward and base-collector junction reverse biased. **[2;CBSE-2012]**

25. (a) Describe briefly, with the help of a diagram, the role of the two important processes involved in the formation of a p-n junction

(b) Name the device which is used as a voltage regulator. Draw the necessary circuit diagram and explain its working



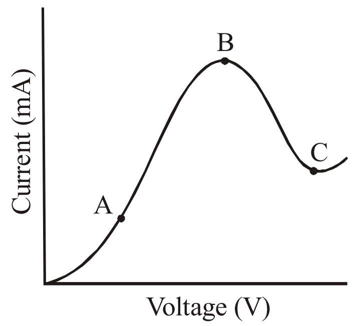
OR

(a) Explain briefly the principle on which a transistor-amplifier works as an oscillator. Draw the necessary circuit diagram and explain its working.

(b) Identify the equivalent gate for the following circuit and write its truth table. **[5; CBSE-2012]**

26. The graph shown in the figure represents a plot of current versus voltage for a given semiconductor. Identity the region, if any, over which the semiconductor has a negative resistance.

[3; CBSE-2013]



27. Draw typical output characteristics of an n-p-n transistor in CE configuration. Show how these characteristics can be used to determine output resistance. **[5; CBSE-2013]**

OR

28. Draw V -1 characteristics of a-p-n junction diode. Answer the following questions, giving reasons:
(i) Why is the current under reverse bias almost independent of the applied potential upto a critical voltage?
(ii) Why does the reverse current show a sudden increase at the critical voltage ?
Name any semiconductor device which operates under the reverse bias in the breakdown region.

[5; CBSE-2013]

29. Draw a circuit diagram of n-p-n transistor amplifier in CE configuration. Under what condition does the transistor acts as an amplifier ? **[2; CBSE-2014]**

30. Explain, with the help of a circuit diagram, the working of a p-n junction diode as a half-wave rectifier. **[2; CBSE-2014]**

31. Write any two distinguishing features between conductors, semiconductors and insulators on the basis of energy band diagrams. **[3; CBSE-2014]**

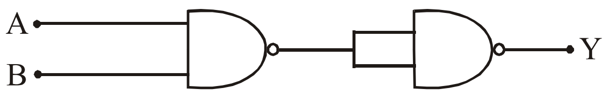
32. With the help of a circuit diagram, explain the working of a junction diode as a full wave rectifier. Draw its input and output waveforms. Which characteristic property makes the junction diode suitable for rectification ? **[3; CBSE-2015]**

33. The outputs of two NOT gates are fed to a NOR gate. Draw the logic circuit of the combination of gates. Write its truth table. Identify the gate equivalent to this circuit. **[3; CBSE-2015]**

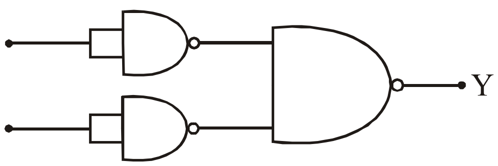
OR

You are given two circuits (a) and (b) as shown in the figures, which consist of NAND gates. Identify the ligic operation carried out by the two. Write the truth tables for each. Identify the gates equivalent to the two circuits.

(a)



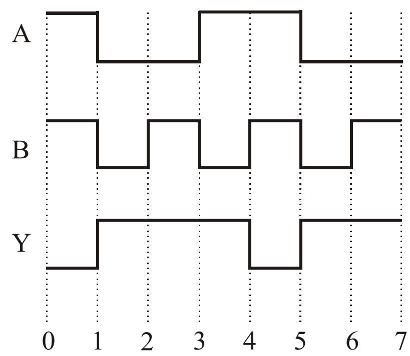
(b)



[3; CBSE-2015]

34. (i) Name two important processes that occur during the formation of a pn junction.
(ii) Draw the circuit diagram of a full wave rectifier along with the inpur and output waveforms. Briefly explain how the output voltage/current is unidirectional. **[CBSE-2016]**

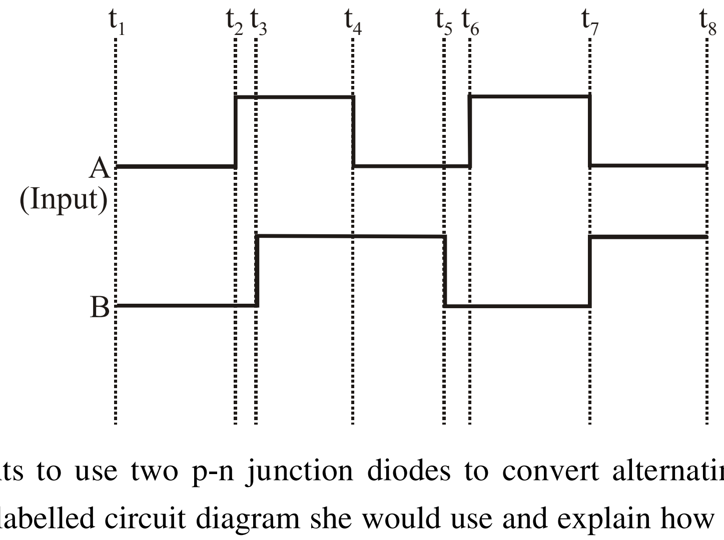
35. (i) Distinguish between a conductor and a semi conductor on the basis of energy band diagram.
(ii) The following figure shows the input waveforms (A, B) and the output waveform (Y) of a gate. Identify the gate, write its truth table and draw its logic symbol. **[CBSE-2016]**



36. (a) In the following diagram, is the junction diode forward biased or reverse biased ? **[CBSE-2017]**

(b) Draw the circuit diagram of a full wave rectifier and state how it works.

37. (a) Write the functions of the three segments of a transistor. **[CBSE-2017]**
(b) The figure shows the input waveforms A and B for 'AND' gate. Draw the output waveform and write the truth table for this logic gate.



38. (a) A student wants to use two p-n junction diodes to convert alternating current into direct current. Draw the labelled circuit diagram she would use and explain how it works.
(b) Give the truth table and circuit symbol for NAND gate. **[CBSE-2018]**

39. Draw the typical input and output characteristics of an n-p-n transistor in CE configuration. Show how these characteristics can be used to determine (a) the input resistance (r_i) and (b) current amplification factor (β). **[CBSE-2018]**

ANSWER KEY

EXERCISE-S

1. Ans. 0.1 Ω

2. Ans.

	R_1	D_1	Total
V	11.35V	0.65V	12V
I	24.15 mA	24.15 mA	24.15 mA
R	470 Ω		
P	274.1 mW	15.7 mW	289.8 mW

3. Ans.

A	B	C	D	E	F	G
0	0	1	1	0	0	1
0	1	1	0	0	1	0
1	0	0	1	1	0	0
1	1	0	0	0	0	1

4. Ans. (i) 10 V (ii) 90 V (iii) 4 mA

EXERCISE-O

SINGLE CORRECT TYPE QUESTIONS

1. Ans. (B) **2. Ans. (B)** **3. Ans. (C)** **4. Ans. (C)** **5. Ans. (B)** **6. Ans. (C)**
7. Ans. (A) **8. Ans. (D)** **9. Ans. (B)** **10. Ans. (B)** **11. Ans. (B)** **12. Ans. (B)**
13. Ans. (C) **14. Ans. (B)** **15. Ans. (B)** **16. Ans. (C)** **17. Ans. (A)** **18. Ans. (A)**
19. Ans. (B) **20. Ans. (C)** **21. Ans. (C)** **22. Ans. (C)** **23. Ans. (D)** **24. Ans. (C)**
25. Ans. (C) **26. Ans. (C)** **27. Ans. (B)** **28. Ans. (C)** **29. Ans. (C)** **30. Ans. (A)**
31. Ans. (D) **32. Ans. (B)** **33. Ans. (A)** **34. Ans. (D)** **35. Ans. (A)** **36. Ans. (C)**
37. Ans. (D) **38. Ans. (C)** **39. Ans. (C)** **40. Ans. (A)** **41. Ans. (B)** **42. Ans. (D)**
43. Ans. (D) **44. Ans. (D)**

MULTIPLE CORRECT TYPE QUESTIONS

45. Ans. (A,B,D) **46. Ans. (A,C,D)** **47. Ans. (B,C)** **48. Ans. (B,D)** **49. Ans. (B,C)**

EXERCISE-JM

1. Ans. (3) **2. Ans. (3)** **3. Ans. (1)** **4. Ans. (3)** **5. Ans. (3)** **6. Ans. (4)**
7. Ans. (4) **8. Ans. (1 or 3)** **9. Ans. (4)** **10. Ans. (4)** **11. Ans. (2)** **12. Ans. (2)**
13. Ans. (2)

SELECTED PROBLEMS FROM JEE-MAINS ONLINE PAPERS

14. Ans. (3) **15. Ans. (2)** **16. Ans. (4)** **17. Ans. (4)** **18. Ans. (2)** **19. Ans. (4)**
20. Ans (2) **21. Ans. (2)** **22. Ans. (3)** **23. Ans. (4)** **24. Ans. (4)** **25. Ans. (2)**
26. Ans. (1) **27. Ans. (3)** **28. Ans. (3)** **29. Ans. (2)** **30. Ans. (12.00)** **31. Ans. (3)**
32. Ans. (2) **33. Ans. (1)** **34. Ans. (1)** **35. Ans. (150.00)**

Important Notes

ALLEN CAREER INSTITUTE KOTA (RAJASTHAN)

Chapter Contents 05

PRINCIPLES OF COMMUNICATION SYSTEM

Important Notes

KEY CONCEPTS

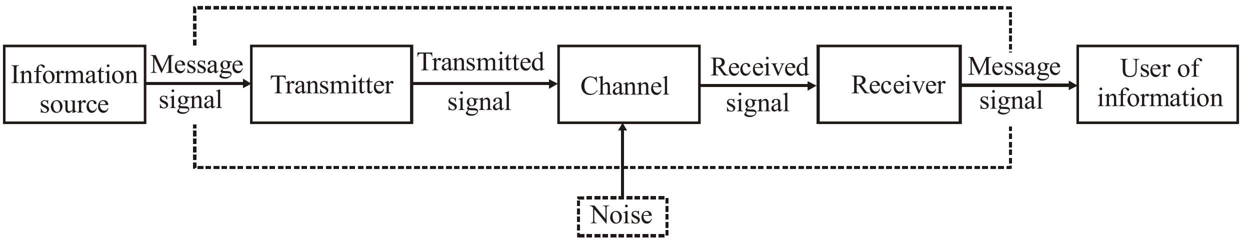
1. INTRODUCTION

Communication means transmission of information. Everyone experiences the need to impart or receive information continuously in the surrounding and for this , we speak, listen, send message by a messenger, use coded signalling methods through smoke or flags or beating of drum etc. and these days we are using telephones, TV, radio, satellite communication etc. The aim of this chapter is to introduce the concepts of communication namely the mode of communication, the need for modulation, production and detection of amplitude modulation.

Elements of a Communication System :

Every communication system has three essential elements-

(i) transmitter (ii) medium/channel (iii) receiver



Transmitter converts the message signal into an electric signal and transmits through channel. The receiver receives the transmitted signal and reconstructs the original message signal to the end user. There are two basic modes of communication: (i) point-to-point and (ii) broadcast.

In point-to-point communication mode, communication takes place over a link between a single transmitter and a receiver as in telephony. In the broadcast mode, there are a large number of receivers corresponding to a single transmitter. Radio and television are most common examples of braoadcast mode of communication. However the communication system can be classified as follows :

Types of Communication Systems

On the basis of nature of Information
(1) Speech Transmission (Radio)
(2) Picture Transmission (TV)
(3) Fascimile Transmission (FAX)
(4) Data Transmission (Internet)

On the basis of signal transmitted
(1) Analog
(2) Digital

On the basis of transmission Channel
(1) Line communication
(a) Two wire Transmission line
(b) Coaxial cable
(c) Optical fibre
(2) Space communication

On the basis of type of modulation
(1) Continuous wave modulation
(a) Amplitude
(b) Frequency
(c) phase
(2) Pulse Modulation
(a) PAM
(b) PTM — PPM, PWM
(c) PCM

Basic terminology Used in Electronic Communication systems :

(i) Transducer. Transducer is the device that converts one form of energy into another. Microphone, photo detectors and piezoelectric sensors are types of transducer. They convert information into electrical signal.

(ii) Signal Signal is the information converted in electrical form. Signals can be analog or digital. Sound and picture signals inTV are analog.

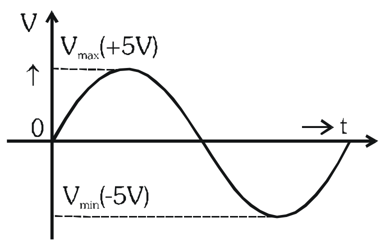
It is defined as a single–valued function of time which has a unique value at every instant of time.

(1) Analog Signal :–

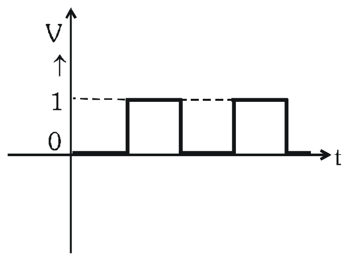
A continuously varying signal (Voltage or Current) is called an analog signal. A decimal number with system base 10 is used to deal with analog signal.

(2) Digital Signal :–

A signal that can have only discrete stepwise values is called a digital signal. A binary number system with base 2 is used to deal with digital signals.



An Analog Signal



An Digital Signal

(iii) Noise : There are unwanted signals that tend to disturb the transmission and processing of message signals. The source of noise can be inside or outside the system.

(iv) Transmitter : A transmitter processes the incoming message signal to make it suitable for transmission through a channel and subsequent reception.

(v) Receiver : A receiver extracts the desired message signals from the received signals at the channel output.

(vi) Attenuation : It is the loss of strength of a signals while propagating through a medium. It is like damping of oscillations.

(vii) Amplification : It is the process of increasing the amplitude (and therefore the strength) of a signal using an electronic circuit called the amplifier. Amplification is absolutely necessary to compensate for the attenuation of the signal in communication systems.

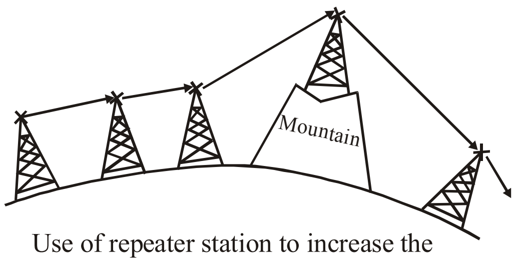
(viii) Range : It is the largest distance between the source and the destination upto which the signal gets received with sufficient strength.

(ix) Bandwidth : It is the frequency range over which an equipment operates or the portion of the spectrum occupied by the signal.

(x) Modulation : The original low frequency message/information signal connot be transmitted to long distances. So, at the transmitter end, information contained in the low frequency message signal is superimposed on a high frequency wave, which acts as a carrier of the information. This process is known as modulation.

(xi) Demodulation : The process of retrieval of original information from the carrier wave at the receiver end is termed as demodulation. This process is the reverse of modulation.

(xii) Repeater : A repeater acts as a receiver and a transmitter. A repeater picks up the signal which is coming from the transmitter, amplifies and retransmits it with a change in carrier frequency. Repeaters are necessary to extend the range of a communication system as shown in figure A communication satellite is basically a repeater station in space.



Use of repeater station to increase the range of communication

BANDWIDTH

Bandwidth of signals :

Different signals used in a comminication system such as voice, music, picture, computer data etc. all have different ranges of frequency. The difference of maximum and minimum frequency in the range of each signal is called bandwidth of that signal.

Bandwidth can be of message signal as well as of transmission medium.

(i) Bandwidth for analog signals

Bandwdith for some analog sinals are listed below :

Signal	Frequency range	Bandwidth required
Speech	300-3100 Hz	3100-300 =2800 Hz
Music	High frequencies produced by musical instrument Audible range =20 Hz - 20 kHz	20 kHz
Picture	-	4.2 MHz
TV	Contains both voice and picture	6 MHz

(ii) Bandwidth for digital signal

Basically digital signals are rectanglar waves and these can be splitted into a superposition of sinusoidal waves of frequencies ν_0, $2\nu_0$, $3\nu_0$, $4\nu_0$, $n\nu_0$, where n is an integer extending to infinity. This implies that the infinite band width is required to reproduce the rectangular waves. However, for practical purposes, higher harmonics are neglected for limiting the bandwidth

Band width of Transmission Medium

Different types of transmission media offer different band width in which some of are listed below

Frequency Bands			
	Service	**Frequency range**	**Remarks**
1	Wire (most common : Coaxial Cable)	750 MHz (Bandwidth)	Normally operated below 18 GHz
2	Free space (radio waves)	Few hundred kHz to GHz	
	(i) Standard AM broadcast	540kHz -1600 kHz	
	(ii) FM	88-108 MHz	
	(iii) Television	54-72 MHz 76-88 MHz 174-216 MHz 420-890 MHz	VHF (Very) high frequencies) TV UHF (Ultra hight frequency) TV
	(iv) Cellular mobile radio	896-901 MHz 840-935 MHz	Mobile to base Station Base station to mobile
	(v) Satellite Communication	5.925-6.425 GHz 3.7 - 4.2 GHz	Uplinking Downlinking
3	Optical communication using fibres	1THz-1000 THz (microwaves-ultra violet)	One single optical fibre offers bandwidth > 100 GHz

Propagation of Electromagnetic Waves :

In case of radio waves communication, an antenna at the transmitter radiates the electromagnetic waves (em waves). The em waves travel through the space and reach the receiving antenna at the other end. As the em wave travels away from the transmitter, their strength keeps on decreasing. Many factors influence the propagation of em waves including the path they follow. The composition of the earth's atmosphere also plays a vital role in the propagation of em waves, as summarised below.

Table 4 Layers of atmosphere and their interaction with the propagating em waves

Atmospheric stratum (layer)	Height over earth's surface (approx)	Exists during	Frequencies most likely affected
1. Troposphere	10 km	Day and night	VHF (upto several GHz)
2. Ionosphere			
(i) D (part of stratosphere)	65-75 km	Day only	Reflects LF, absorbs MF & HF to some degree
(ii) E (part of stratosphere)	100 km	Day only	Helps surface waves, reflects HF
(iii) F_1 (Part of Mesosphere)	170-190 km	Daytime, merges with F_2 at night	Partially absorbs HF waves yet allowing them to reach F_2
(iv) F_2 (Thermosphere)	300 km at night, 250-400 km during daytime	Day and night	Efficiently reflects HF waves particularly at night

Ground Wave Propagation :

(a) The radio waves which travel through atmosphere following the surface of earth are known as ground waves or surface waves and their propagation is called ground wave propagation or surface wave propagation.

(b) The ground wave transmission becomes weaker with increase in frequency because more absorption of ground waves takes place at higher frequency during propagation through atmosphere.

(c) The ground wave propagation is suitabel for low and medium frequency i.e. upto 2 or 3 MHz only.

(d) The ground wave propagation is generally used for local band broadcasting and is commonly called medium wave.

(e) The maximum range of ground or surface wave propagation depends on two factors :

(i) The frequency of the radio waves and

(ii) Power of the transmitter

Sky Wave Propagation :

(a) The sky waves are the radio waves of frequency between 2 MHz to 30 MHz.

(b) The ionoopheric layer acts as a reflector for a certain range of frequencies (3 to 30 MHz). Electromagnetic waves of frequencies higher than 30 MHz penetrate the ionosphere and escape.

(c) The highest frequency of radiowaves which when sent straight (i.e. normally) towards the layer of ionosphere gets refelcted from ionosphere and returns to the earth is called critical frequency.. If is given by $f_c = 9\ (N_{max})^{1/2}$, where N is the number density of electron/m^3.

Space wave propagation :

(a) The space waves are the radiowaves of very high frequency (i.e. between 30 MHz. to 300 MHz or more).

(b) the space waves can travel through atmosphere from transmitter antenna to receiver antenna either derectly or after reflection from ground in the earth's troposphere region. That is why the space wave propagation is also called as tropospherical propagation or line of sight propagation.

(c) The range of communication of space wave propagation can be increased by increasing the heights of transmitting and receiving antenna.

(d) If the transmitting antenna is at a height h_T, then you can show that the distance to the horizontal d_T is given as $\boxed{d_T = \sqrt{2Rh_T}}$, where R is the radius of the earth (approximately 6400 km). d_T is also called the radio maximum line-of sight distance d_m between the two antennas having heights h_T and h_R above the earth is given by :

$$\boxed{d_M = \sqrt{2Rh_T} + \sqrt{2Rh_R}}$$

where h_R is the height of receiving antenna.

Modulation

* It is a process by which any electrical signal called input / baseband or modulating signal, is mounted onto another signal of high frequency which is known as carrier signal.
* It is defined as the process by which some characteristic (called parameter) of carrier signal is varied in accordance with the instantaneous value of the baseband signal.
* The signal which results from this process is known as modulated signal.

Need for Modulation :

(i) To aviod interference :

If many modulating signals travel directly through the same transmission channel, they will interfere with each other and result in distortion.

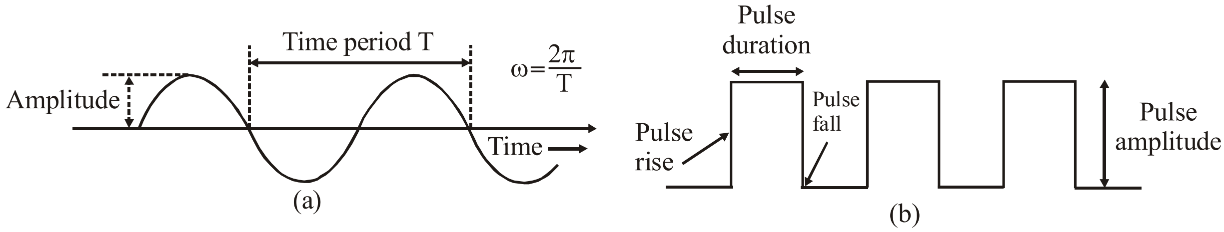
(ii) To design antennas of practicable size :

The minimum height of antenna (not of antenna tower) should be $\lambda/4$ where λ is wavelength of modulating signal. This minimum size becomes impracticable because the frequency of the modulating signal can be upto 5 kHz which corresponds to a wavelength of $3 \times 10^8/5 \times 10^3 = 60$ km. This will require an antenna of the minimum height of $\lambda/4 = 15$ km. This size of an antenna is not practical.

(iii) Effective Power Radiated by an Antenna :

A theoretical study of radiation from a linear antenna (length ℓ) shows that the power radiated is proportional to (frequency)^2 i.e. $(\ell/\lambda)^2$. For a good transmission, we need high powers and hence this also points out to the need of using high frequency transmission.

The above discussion suggests that there is a need for translating the original low frequency baseband message signal into high frequency wave before transmission. In doing so, we take the help of a high frequency signal, which we already know now, is known as the carrier wave, and a process known as modulation which attaches information to it. The carrier wave may be continuous (sinusoidal) or in the form of pulses, as shown in figure



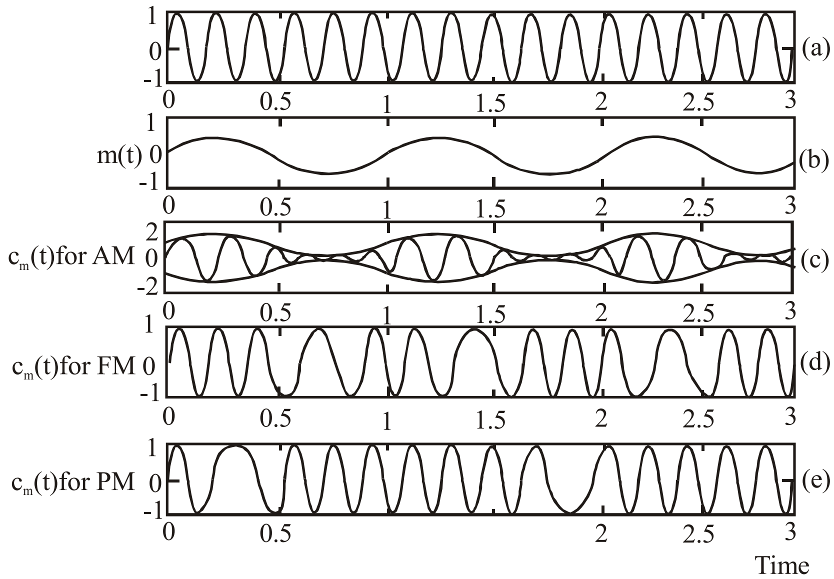
(a) (b)

Carrier wave : Sinusoidal

A sinusoidal carrier wave can be represented as

$c(t) = A_C \sin(\omega_c t + \phi)$

where c(t) is the signal strength (voltage or current), A_C is the amplitude, ω_c $(= 2\pi f_c)$ is the angular frequency and ϕ is the initial phase of the carrier wave. Thus, modulation can be affected by varying, any of three parameters, viz A_c, ω_c and ϕ, of the carrier wave can as per the parameter of the message or information signal. This results in three types of modulation : (i) Amplitude modulation (AM) (ii) Frequency modulation (FM) and (iii) Phase modulation (PM), as shown in figure.



Modulation of a carrier wave : (a) a sinusoidal carrier wave
(b) a modulating signal : (c) amplitude modulatin :
(d) frequency modulation : and (e) phase modulation

Carrier Wave Pulses :

Similarly, the significant characteristics of a pulse are : Pulse Amplitude, Pulse duration or pulse Width, and pulse Position (denoting the time of rise or fall of the pulse amplitude) Hence, different types of pulse modulation are (a) pulse amplitude modulation (PAM), (b) Pulse duration modulation (PDM) or pulse width modulation (PWM), and (c) Pulse position modulation (PPM).

Ex.1 A separate high freq. wave (i.e. carrier wave) is needed in modulation why ?

Ans. This is because we cannot change any of the characteristics (amplitude, frequency or phase) of the audio signal as this would change the message to be communicated. So keeping the audio signal same, the amplitude of freq. or phase of the high freq. carrier wave is modified in accordance with the modulating (i.e. audio signal) signal.

Amplitude Modulation :

In amplitude modulation the amplitude of the carrier is varied in accordance with the information signals. Let $c(t) = A_c \sin\omega_c t$ represent carrier wave and $m(t) = A_m \sin \omega_m t$ represent the message or the modulating signal where $\omega_m = 2\pi f_m$ is the angular frequency of the message signal. The modulated signal $c_m(t)$ can be written as

$c_m(t) = (A_c + A_m \sin \omega_m t) \sin \omega_c t$

$$= A_c\left(1+\frac{A_m}{A_c}\sin\omega_m t\right)\sin\omega_c t \qquad .....(1)$$

Note that the modulated signal now contains the message signal & it can be written as :

$c_m(t) = A_c \sin\omega_c t + \mu A_c \sin\omega_m t \sin\omega_c t \qquad ......(2)$

Here **$\mu = A_m/A_c$ is the modulation index**

Often, μ is expressed in percentage and is called the percentage modulation. Importance of modulation index is that it determine the quality of the transmitted signal. When modulation index is small, variation in carrier amplitude will be small. Therefore, audio signal being transmitted will be weak. As the modulation index increases, the audio signal on reception becomes clearer. If the modulation index becomes greater than one, the signal gets lost partially.

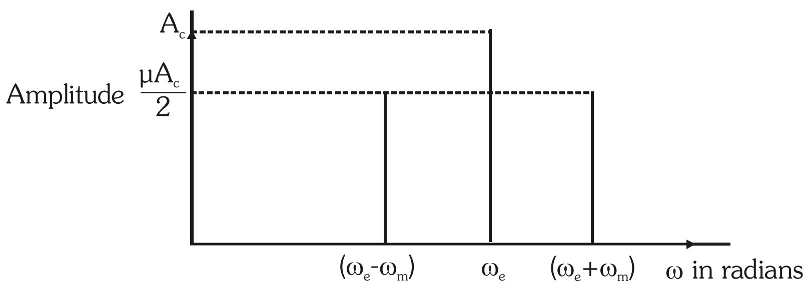
If a carrier wave is modulated by several sine waves the total modulated index m_t is given by

$$m_t = \sqrt{m_1^2 + m_2^2 + m_3^2 + ...}$$

Using the trignomatric relation sinA sinB = ½ (cos (A – B) – cos (A + B), we can write $c_m(t)$ of eq. (15.4)as

$$c_m(t) = A_c \sin\omega_c t + \frac{\mu A_c}{2}\cos(\omega_c - \omega_m)t - \frac{\mu A_c}{2}\cos(\omega_c + \omega_m)t \qquad ......(3)$$

Here $\omega_c - \omega_m$ and $\omega_c + \omega_m$ are respectively called the called the lower side and upper side frequencies. The modulated signal now consists of the carrier wave of frequency ω_c plus two sinusoidal waves each with a frequency slightly different from, know as side bands. The frequency spectrum of the amplitude modulated signal is shown in figure :



As long as the broadcast frequencies (carrier waves) are sufficiently spaced out so that sidebands do not overlap, different stations can operate without interfering with each other.

$f_{SB} = f_c \pm f_m$

$\therefore$ Frequency of lower side band is

$f_{LSB} = f_c - f_m$ ... (4)

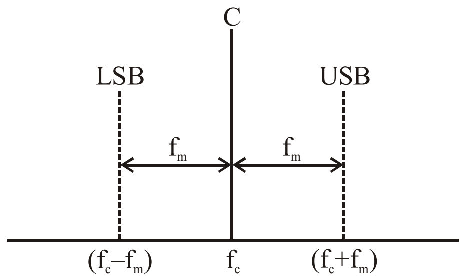
and frequency of upper side band is

$f_{USB} = f_c + f_m$

Band width of amplitude modulated wave is

$= f_{USB} - f_{LSB}$

$= (f_f + f_m) - (f_c - f_m) = 2f_m$ .... (5)



Band width = twice the frequency of the modulating signal

Phase modulation & frequency modulation are 2 different types of angular modulation.

Power in AM waves : Power dissipated in any circuit $P = \dfrac{V_{rms}^2}{R}$

Hence : (i) Carrier power $P_c = \dfrac{\left(\dfrac{E_c}{\sqrt{2}}\right)^2}{R} = \dfrac{E_c^2}{2R}$

(ii) Total power of side bands $P_{sb} = \dfrac{\left(\dfrac{m_a E_c}{2\sqrt{2}}\right)^2}{R} \times 2 = \dfrac{m_a^2 E_c^2}{4R}$

(iii) Total power of AM wave $P_{Total} = P_c + P_{ab} = \dfrac{E_c^2}{2R}\left(1 + \dfrac{m_a^2}{2}\right)$

(iv) $\dfrac{P_t}{P_c} = \left(1 + \dfrac{m_a^2}{2}\right)$ and $\dfrac{P_{ab}}{P_t} = \dfrac{m_a^2/2}{\left(1 + \dfrac{m_a^2}{2}\right)}$

(v) Maximum power in the AM (without distortion) will occur when $m_a = 1$

i.e., $P_t = 1.5\ P = 3P_{ab}$

(vi) If I_c = Unmodulated current and I_t = total or modulated current

$$\Rightarrow \frac{P_t}{P_c} = \frac{I_t^2}{I_c^2} \Rightarrow \frac{I_t}{I_c} = \sqrt{\left(1 + \frac{m_a^2}{2}\right)}$$

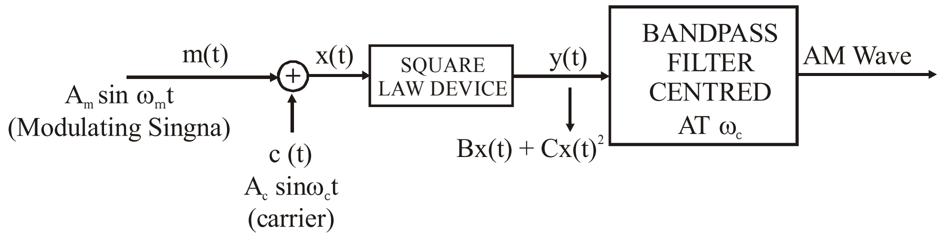
Ex.2 A message signal of frequency 10 kHz and peak voltage of 10 volts is used to modulate a carrier of frequency 1 Mhz and peak voltage of 20 volts. Determine (a) modulation index, (b) the side bands produced.

Sol. (a) Modulation index = 10/20 = 0.5

(b) The side bands are at (1000 + 10 kHz) = 1010 kHz and (1000–10 kHz) = 990 kHz.

Production of Amplitude modulated Wave :

Ampitude modulation can be produced by a veriety of methods. A conceptually simple method is shown in the block diagram of figure.



Here the modulating signal $A_m \sin \omega_m t$ is added to the carrier signal $A_c \sin \omega_c t$ to produce the signal x (t). This signal $x(t) = A_m \sin \omega_m t + A_c \sin\omega_c t$ is passed through a square law device which is a non-linear device which produces an output

$y(t) = B\,x(t) + Cx^2(t)$ ......(4)

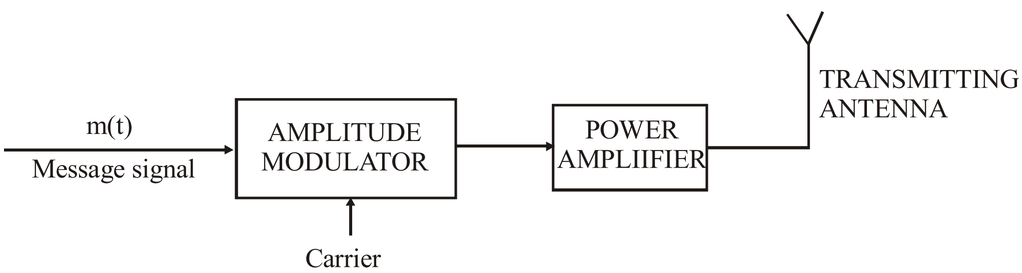
where B and C are constants. Thus,

$$y(t) = BA_m \sin\omega_m t + BA_c \sin \omega_c t$$
$$+ C[A_m^2 \sin^2 \omega_m t + A_c^2 \sin^2 \omega_c t + 2A_m A_c \sin\omega_m t \sin\omega_c t] \quad ......(5)$$
$$= BA_m \sin\omega_m t + BA_c \sin \omega_c t$$
$$\frac{CA_m^2}{2} + A_c^2 - \frac{CA_m^2}{2}\cos 2\omega_m t - \frac{CA_c^2}{2}\cos 2\omega_c t$$
$$+ CA_m A_c \cos(\omega_c - \omega_m)t - CA_m A_c \cos(\omega_c + \omega_m)t \quad ......(6)$$

where the trigonometric relations $\sin^2 A = (1 - \cos 2A)/2$ and the relation for sinA sinB mentioned earlier are used.

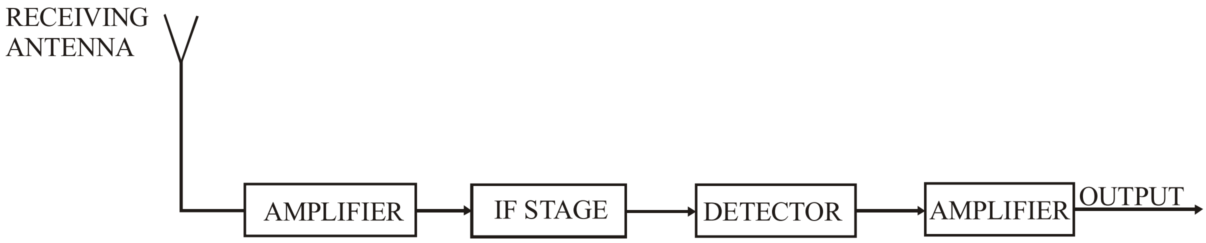
In equation (6), there is a dc term C/2 $(A_m^2 + A_c^2)$ and sinusoids of frequencies ω_m, $2\omega_m$, $\omega_c - \omega_m$ and $\omega_c + \omega_m$. The output of the band pass filter therefore is of the same form as equation (3) and is therefore an AM wave.

It is to be mentioned that the modulated signal connot be transmitted as such. The modulator is to be followed by a power amplifier which provides the necesary power and then the modulated signal is fed to an antenna of appropriate size for radiation as shown in figure.

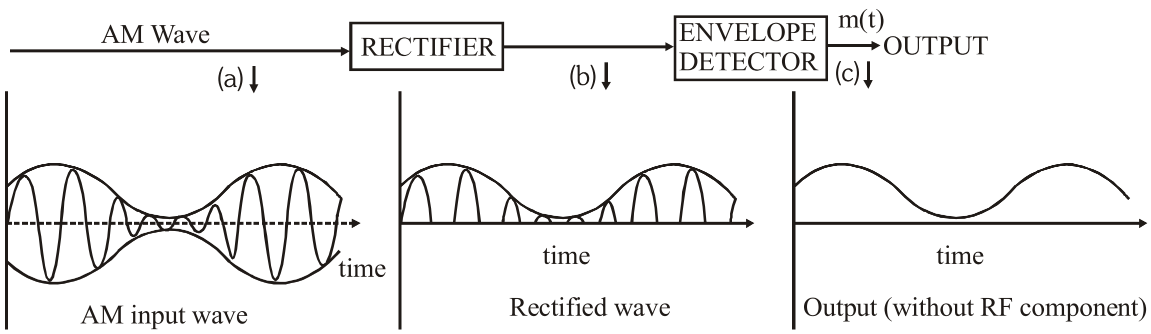


Detection of Amplitude Modulated Wave :

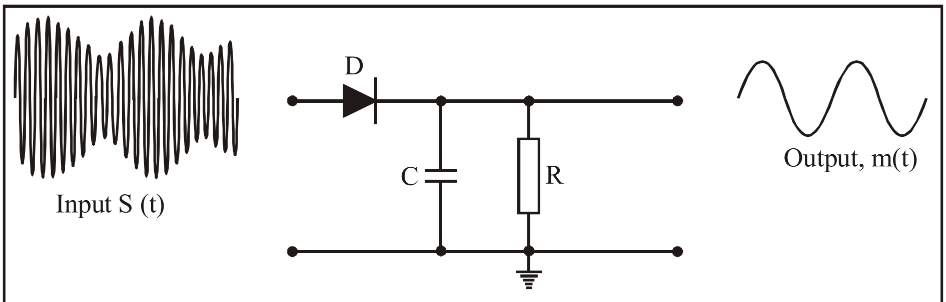
The transmitted message gets attenuated in propagating through the channel. The receiving antenna is therefore to be followed by an amplifier and a detector. In addition, to facilitate further processing, the carrier frequency is usually changed to a lower frequency by what is called an intermediate frequency (IF) stage preceding the detection. The detected signal may not be strong enough to be made use of and hence is required to be amplified. A block diagram of a typical receiver is shown in figure.



Detection is the process of recovering the modulating signal from the modulated carrier wave. We just saw that the modulated carrier wave contains the frequencies ω_c and $\omega_c \pm \omega_m$. In order to obtain the original message signal m(t) of angular frequency ω_m, a simple method is shown in the from of a block diagram in figure.



The modulated signal of the form given in (a) of above figure is passed through a rectifier to produce the output shown in (b). This envelope of signal (b) is the message signal In order to retrieve m(t), the signal is passed through an envelope detector (which may consist of a simple RC circuit).



Envelope Detector (AM Demodulator/Detector)

This is essentially just a half wave rectifier which charges a capacitor to a voltage to the peak voltage of the incoming AM waveform, S(t). When the input wave's amplitude increases, the capacitor voltage in increased via the rectifying diode. When the input's amplitude falls, the capacitor voltage is reduced by being discharged by a 'bleed' resistor, R. The main advantage of this form of AM Demodulator is that it is very simple and cheap!

The circuit relies upon the behaviour of the diode-allowing current through when the input is +ve with respect to the capacitor voltage, hence 'topping up' the capacitor voltage to the peak level, but blocking any current from flowing back out through the diode when the input voltage is below the capacitor voltage.

Consider what happens when we have a carrier frequency, f_c, and use an envelope detector whose time constant, τ = (RC). The time between successive peaks of the carrier will be $T = \frac{1}{f_c}$

Each peak will charge the capacitor to some voltage, V_{peak}, which is proportional to the modulated amplitude of the AM wave. Between each peak and the next the capacitor voltage will therefore be discharged to

$$V'_{peak} = V_{peak} \text{ Exp } \{-T/\tau\}$$

which, provided that $T << \tau$, is approximately the same as

$$V'_{peak} \approx V_{peak} \ [1-T/\tau]$$

The peak-to-peak size of the ripple, ΔV, will therefore be

$$\Delta V \approx \frac{V_{peak}T}{\tau} = \frac{V_{peak}}{f_c\tau}$$

A sudden, large reduction in the amplitude of the input AM wave means that capacitor charge isn't being 'topped up' by each cycle peak. The capacitor voltage therefore falls exponentially until it reaches the new, smaller, peak value. In practice the modulating signal is normally restricted to a specific frequency range. This limits the maximum rate of fall of the AM wave's amplitude. We can therefore hope to avoid negative peak clipping by arranging that the detector's time constant $\tau << t_m$ where

$$t_m = 1/f_m$$

and f_m is the highest modulation frequency used in a given situation.

The above implies that we can avoid negative peak clipping by choosing a small value of τ. However, to minimise ripple we want to make τ as large as possible. In practice we should therefore choose a value

$$1/f_m >> \tau >> 1/f_c$$

to minimise the signal distortions caused by these effects. This is clearly only possible if the modulation frequency $f_m << f_c$. Envelope detector only work satisfactorily when we ensure this inequality is true. With the modulation index and the resistor the capacitor can be computed by

$$C \leq \frac{\sqrt{\left(\frac{1}{m}\right)^2 - 1}}{2\pi R f_m(\max)}$$

EXERCISE-S

1. Is it necessary for a transmitting antenna to be at the same height as that of the receiving antenna for 'line-of-sight communication? A TV transmitting antenna is 81m tall. How much service area can it cover if the receiving antenna is at the ground level?

PC0001

2. A carrier wave of peak voltage 12 V is used to transmit a message signal. What should be the peak 'voltage of the modulating signal in order to have a modulation index of 75%?

PC0002

3. For an amplitude modulated wave, the maximum amplitude is found to be 10V while the minimum amplitude is found to be 2V. Determine the modulation index μ.

PC0003

4. If the sum of the heights of transmitting and receiving antennas in line of sight of communication is fixed at h, show that the range is maximum when the two antennas have a height h/2 each.

PC0004

EXERCISE-O

SINGLE CORRECT TYPE QUESTIONS

1. If a carrier wave of 1000 kHz is used to carry the signal, the length of transmitting antenna will be equal to :-

(A) 3 m (B) 30m (C) 300 m (D) 3000 m

PC0005

2. The maximum range of ground or surface wave propagation depends on :-

(A) the frequency of the radio waves only (B) power of the transmitter only

(C) both of them (D) none of them

PC0006

3. For television broadcasting, the frequency employed is normally :-

(A) 30-300MHz (B) 30-300 GHz (C) 30-300KHz (D) 30-3OOHz-

PC0007

4. The audio signal :-

(A) can be sent directly over the air for large distance

(B) cannot be sent directly over the air for large distance

(C) possess very high frequency

(D) none of the above

PC0008

5. For a carrier frequency of 100 kHz and a modulating frequency of 5 kHz what is the width of AM transmission-

(A) 5 kHz (B) 10kHz (C) 20 kHz (D) 200 KHz

PC0009

6. Three waves A, B and C of frequencies 1600 kHz, 5 MHz and 60 MHz, respectively are to be transmitted from one place to another. Which of the following is the most appropriate mode of communication :

(A) A is transmitted via space wave while B and C are transmitted via sky wave.

(B) A is transmitted via ground wave, B via sky wave and C via space wave.

(C) B and C are transmitted via ground wave while A is transmitted via sky wave.

(D) B is transmitted via ground wave we while A and C are transmitted via space wave.

PC0010

7. A speech signal of 3kHz is used to modulate a carrier signal of frequency 1 MHz, using amplitude modulation. The frequencies of the side bands will be

(A) 1.003 MHz and 0.997 MHz. (B) 3001 kHz and 2997 kHz.

(C) 1003 kHz and 1000 kHz. (D) 1 MHz and 0.997 MHz.

PC0011

8. A message signal of frequency ω_m is superposed on a carrier wave of frequency ω_e to get an amplitude mediated wave (AM) The frequency of the AM wave will be

(A) ω_m (B) ω_e (C) $\frac{\omega_e + \omega_m}{2}$ (D) $\frac{\omega_e - \omega_m}{2}$

PC0012

9. A basic communication system consists of

(A) transmitter (B) information source. (C) user of information.

(D) channel (E) receiver.

Choose the correct sequence in which these are arranged in a basic communication system :-

(A) ABCDE (B) BADEC (C) BDACE (D) BEADC

PC0013

10. **Statement 1 :** Skywave can not be observed on moon.

Statement 2 : Atmosphere of variable refractive index is require for propagation of skywave.

(A) Both Statement-1 and Statement-2 are true, and Statement-2 is the correct explanation of Statement-1

(B) Both Statement-1 and Statement-2 are true but Statement-2 is not the correct explanation of Statement- 1.

(C) Statement-1 is true but Statement-2 is false.

(D) Statement-1 is false but Statement-2 is true.

PC0014

11. **Statement 1 :** Ground wave communication is effective only allow frequencies in the range 500kHz to about 1500 kHz.

Statement 2 : The decrease in the intensity of the signal due to absorption by the earth and its atmosphere is higher for higher frequencies.

(A) Both Statement-1 and Statement-2 are true, and Statement-2 is the correct explanation of Statement-1.

(B) Both Statement-1 and Statement-2 are true but Statement-2 is not the correct explanation of Statement-I .

(C) Statement-1 is true but Statement-2 is false.

(D) Statement-1 is false but Statement-2 is true.

PC0015

MULTIPLE CORRECT TYPE QUESTIONS

12. An audio signal of I5kHz frequency cannot be transmitted over long distances without modulation because

(A) the size of the required antenna would be at least 5 km which is not convenient.

(B) the audio signal cannot be transmitted through skywaves.

(C) the size of the required antenna would be at least 20 km, which is not convenient.

(D) effective power transmitted would be very low, if the size of the antenna is less than 5 km.

PC0016

13. Audio sine waves of 3 kHz frequency are used to amplitude modulate a carrier signal of 1.5 MHz. Which of the following statements are true?

(A) The side band frequencies are 1506 kHz and 1494 kHz.

(B) The bandwidth required for amplitude modulation is 6kHz.

(C) The bandwidth required for amplitude modulation is 3 MHz.

(D) The side band frequencies are 1503 kHz and 1497 kHz.

PC0017

EXERCISE-JM

1. This questions has Statement-1 and Statement-2. Of the four choice given after the statements, choose the one that best describes the two statements.

Statement-1 : Sky wave signals are used for long distance radio communication. These signals are in general, less stable than ground wave signals. **[AIEEE-2011]**

Statement-2 : The state of ionosphere varies from hour to hour, day to day and season to season.

(1) Statement-1 is true, Statement-2 is true, Statement-2 is the correct explanation of statement-1

(2) Statement-1 is true, Statement-2 is true, Statrment-2 is not the correct explanation of Statement-1

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

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

PC0018

2. A radar has a power of 1 kW and is operating at a frequency of 10 GHz. It is located on a mountain top of height 500 m. The maximum distance up to which it can detect object located on the surface of the earth (Radius of earth = 6.4×10^6 m) is : **[AIEEE-2012]**

(1) 40 km (2) 64 (3) 80 km (4) 16km

PC0019

3. A diode detector is used to detect an amplitude modulated wave of 60% modulation by using a condenser of capacity 250 pico farad in parallel with a load resistance 100 kilo ohm. Find the maximum modulated frequency which could be detected by it. **[JEE Main-2013]**

(1) 10.62kHz (2) 5.31 MHz (3) 5.31 kHz (4) 10.62MHz

PC0020

4. A single of 5 kHz frequency is amplitude modulated on a carrier wave of frequency 2 MHz. The frequencies of the resultant signal is/are - **[JEE Main-2015]**

(1) 2005 kHz, 2000 kHz and 1995 kHz (2) 2000 kHz and 1995 kHz

(3) 2 MHz only (4) 2005 kHz and 1995 kHz

PC0021

5. Choose the correct statement : **[JEE Main-2016]**

(1) In frequency modulation the amplitude of the high frequency carrier wave is made to vary in proportion to the frequency of the audio signal.

(2) In amplitude modulation the amplitude of the high frequency carrier wave is made to vary in proportion to the amplitude of the audio signal.

(3) In amplitude modulation the frequency of the high frequency carrier wave is made to vary in proportion to the amplitude of the audio signal.

(4) In frequency modulation the amplitude of the high frequency carrier wave is made to vary in proportion to the amplitude of the audio signal.

PC0022

6. In amplitude modulation, sinusoidal carrier frequency used is denoted by ω_c and the signal frequency is denoted by ω_m. The bandwidth ($\Delta\omega_m$) of the signal is such that $\Delta\omega_m << \omega_c$. Which of the following frequencies is not contained in the modulated wave ? **[JEE Main-2017]**

(1) $\omega_m + \omega_c$ (2) $\omega_c - \omega_m$ (3) ω_m (4) ω_c

PC0023

7. A telephonic communication service is working at carrier frequency of 10 GHz. Only 10% of it is utilized for transmission. How many telephonic channels can be transmitted simultaneously if each channel requires a bandwidth of 5 kHz ? **[JEE Main-2018]**

(1) 2×10^4 (2) 2×10^5 (3) 2×10^6 (4) 2×10^3

PC0024

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8. In a communication system operating at wavelength 800 nm, only one percent of source frequency is available as signal bandwidth. The number of channels accomodated for transmitting TV signals of band width 6 MHz are (Take velocity of light $c = 3 \times 10^8$m/s,$h = 6.6 \times 10^{-34}$ J-s)

[JEE Main-2019_Jan]

(1) 3.75×10^6 (2) 4.87×10^5 (3) 3.86×10^6 (4) 6.25×10^5

PC0025

9. The modulation frequency of an AM radio station is 250 kHz, which is 10% of the carrier wave. If another AM station approaches you for license what broadcast frequency will you allot ?

[JEE Main-2019_Jan]

(1) 2750 kHz (2) 2000 kHz (3) 2250 kHz (4) 2900 kHz

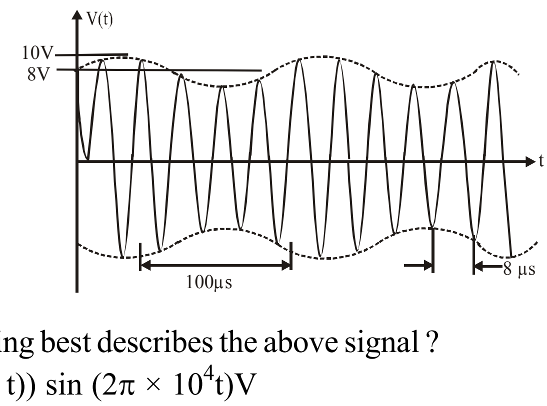
PC0026

10. A TV transmission tower has a height of 140 m and the height of the receiving antenna is 40 m. What is the maximum distance upto which signals can be broadcasted from this tower in LOS(Line of Sight) mode ? (Given : radius of earth = 6.4×10^6m). **[JEE Main-2019_Jan]**

(1) 80 km (2) 48 km (3) 40 km (4) 65 km

PC0027

11. An amplitude modulated signal is plotted below :- **[JEE Main-2019_Jan]**



Which one of the following best describes the above signal ?

(1) $(9 + \sin(2.5\pi \times 10^5 t)) \sin(2\pi \times 10^4 t)$V

(2) $(9 + \sin(4\pi \times 10^4 t)) \sin(5\pi \times 10^5 t)$V

(3) $(1 + 9\sin(2\pi \times 10^4 t)) \sin(2.5\pi \times 10^5 t)$V

(4) $(9 + \sin(2\pi \times 10^4 t)) \sin(2.5\pi \times 10^5 t)$V

PC0028

12. A 100 V carrier wave is made to vary between 160 V and 40 V by a modulating signal. What is the modulation index ? **[JEE Main-2019_Jan]**

(1) 0.6 (2) 0.5 (3) 0.3 (4) 0.4

PC0029

13. The physical sizes of the transmitter and receiver antenna in a communication system are :-

(1) proportional to carrier frequency

(2) inversely proportional to modulation frequency

(3) inversely proportional to carrier frequency

(4) independent of both carrier and modulation frequency **[JEE Main-2019_April]**

PC0030

14. A message signal of frequency 100 MHz and peak voltage 100 V is used to execute amplitude modulation on a carrier wave of frequency 300 GHz and peak voltage 400 V. The modulation index and difference between the two side band frequencies are : **[JEE Main-2019_April]**

(1) 4; 1×10^8 Hz (2) 0.25; 1×10^8 Hz (3) 4; 2×10^8 Hz (4) 0.25; 2×10^8 Hz

PC0031

15. Given below in the the left column are different modes of communication using the kinds of waves given the right column. **[JEE Main-2019_April]**

A.	Optical Fibre communication	P.	Ultrasound
B.	Radar	Q.	Infrared Light
C.	Sonar	R.	Microwaves
D.	Mobile Phones	S.	Radio Waves

(1) A-S, B-Q, C-R, D-P (2) A-R, B-P, C-S, D-Q

(3) A-Q, B-S, C-R, D-P (4) A-Q, B-S, C-P, D-R

PC0032

CBSE PREVIOUS YEAR'S QUESTIONS

1. A.T.V. tower has a height of 400 m at a given place. Calculate as coverage range, if the radius of the earth is 6400 km. **[2; CBSE-2004]**

2. Why is shortwave bind used for long distance radio broadcast? **[1; CBSE-2004]**

3. Distinguish between analog and digital communication Write any two modulation techniques employed for the digital data. Describe briefly any one of the techniques used. **[3; CBSE-2005]**

4. A ground receiver stations receiving a signal at (a) 5MHz and (b) 100 MHz, transmitted from a ground transmitter at a height of 300 m located at a distance of 100 km. Identify whether it is coming via space wave or sky wave propagation or satellite transponder. (Given the value of radius of the earth is 6400 km and maximum electron density, N_{max} = 1012 m^{-3}).**[3; CBSE-2005]**

5. Consider an optical communication system operating at λ – 800 nm. Suppose, only 1% of the optical source frequency is the available channel band-width for optical communication. How many channels can be accommodated for transmitting **[3; CBSE-2006]**

(a) audio-signals requiring a band-width of 8 kHz,

(b) video TV signals requiring an approximate band-width of 4.5 MHz? Support your answer with suitable calculations.

6. Distinguish between frequency modulation and amplitude modulation. Why is an FM signal less susceptible to noise than an AM signal? **[3; CBSE-2006]**

7. Give any one difference between FAX and e-mail systems of communication. **[1; CBSE-2006]**

8. What is modulation? Explain the need of modulating a low frequency information signal. With the help of diagrams, differentiate between PAM and PDM. **[3; CBSE-2007]**

9. What should be the length of dipole antenna for a carrier wave of frequency 6 x 10^8 Hz? **[1; CBSE-2007]**

10. A transmitting antenna at the top of a tower has a height of 36m and the height of the receiving antenna is 49m. What is the maximum distance between them for satisfactory communication in the LOS mode? (Radius of earth = 6400km). **[3; CBSE-2008]**

11. What is meant by term 'modulation'? Draw a block diagram of a simple modulator for obtaining an AM signal. **[2; CBSE-2009]**

12. Why is high frequency carrier waves used for transmission? **[2; CBSE-2009]**

13. By what percentage will the transmission range of a TV tower be affected when the height of tower is increased by 21%? **[12; CBSE-2009]**

14. Write two factors justifying the need of modulating a signal. A carrier wave of peak voltage 12 V is used to transmit a message signal. What should be the peak voltage of the modulating signal in order to have a modulation index of 75% ? **[12; CBSE-2010]**

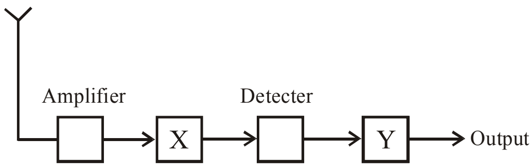
15. Which mode of propagation is used by short wave broadcast services having frequency range from a few MHz upto 30 MHz ? Explain diagrammatically how long distance communication can be achieved by this mode. Why is there an upper limit to frequency of waves used in this mode ? **[3; CBSE-2010]**

16. What is sky wave communication ? Why is this mode of propagation restricted to the frequencies only upto few MHz? **[2; CBSE-2011]**

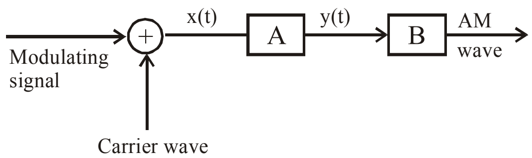
17. Write briefly any two factors which demonstrate the need for modulating a signal. Draw a suitable diagram to show amplitude modulation using a sinusoidal signal as the modulating signal. **[3; CBSE-2011]**

18. Mention three different modes of propagation used in communication system. Explain with the help of a diagram how long distance communication can be achieved by ionospheric reflection of radio waves. **[3; CBSE-2012]**

19. In the given block diagram of a receiver, identify the boxes labeled as X and Y and write their functions. **[2; CBSE-2012]**



20. In the block diagram of a simple modulator for obtaining an AM signal, shown in the figure, identify the boxes A and B. Write their functions. **[12; CBSE-2013]**



21. Name the type of waves which are used for line of sight (LOS) communication. What is the range of their frequencies?
A transmitting antenna at the top of a tower has a height of 20 m and the height of the receiving antenna is 45 m. Calculate the maximum distance between them for satisfactory communication in LOS mode. (Radius of the Earth = 6.4 x 10^6m) **[3; CBSE-2013]**

22. Write the functions of the following in communication systems.
(i) Transmitter (ii) Modulator **[2; CBSE-2014]**

23. Write two basic modes of communication Explain the process of amplitude modulation. Draw a schematic sketch showing how amplitude modulated signal is obtained by superposing a modulating signal over a sinusoidal carrier wave. **[3; CBSE-2014]**

24. What is the function of a band pass filter used in a modulator for obtaining AM signal ? **[1; CBSE-2015]**

25. Differentiate between amplitude modulated (AM) and frequency modulated (FM) waves by drawing suitable diagrams. Why is FM signal preferred over AM signal ? **[2; CBSE-2015]**

26. Name the three different modes of propagation in a communication system. **[3; CBSE-2015]**
State briefly why do the electromagnetic waves with frequency range from a few MHz upto 30 MHz can reflect back to the earth. What happens when the frequency range exceeds this limit ?

27. A signal of 5 kHz frequency is amplitude modulated on a carrier wave of frequency 2 MHz. What are the frequencies of the side bands produced ? **[CBSE-2016]**

28. Why is base band signal not transmitted directly ? Give any two reasons. **[CBSE-2016]**

29. What is space wave propagation? State the factors which limit its range of propagation. Derive an expression for the maximum line of sight distance between two antennas for space wave propagation. **[CBSE-2016]**

30. (a) How is amplitude modulation achieved ?

(b) The frequencies of two side bands in an AM wave are 640 kHz and 660 kHz respectively. Find the frequencies of carrier and modulating signal. What is the bandwidth required for amplitude modulation ? **[CBSE-2017]**

31. Draw a block diagram of a generalized communication system. Write the functions of each of the following: **[CBSE-2017]**

(a) Transmitter

(b) Channel

(c) Receiver

32. Which modes of propagation is used by short wave broadchast services? **[CBSE-2018]**

33. A carrier wave of peak voltage 15 V is used to transmit a message signal. Find the peak voltage of the modulating signal in order to have a modulation index of 60%. **[CBSE-2018]**

34. (a) Give three reasons why modulation of a message signal is necessary for long distance transmission.

(b) Show graphically an audio signal, a carrier wave and an amplitude modulated wave.

[CBSE-2018]

ANSWER KEY

EXERCISE-S

1. **Ans.** No. Service area will be A = $\pi d_7^2 = \frac{22}{7} \times 162 \times 6.4 \times 10^6 = 3258$ km^2.

2. **Ans.** $\mu = 0.75 = \frac{A_m}{A_c}$; $A_m = 0.75 \times 12 = 9V$

3. **Ans.** Since the AM wave is given by ($A_c + A_m$) sin ω_m t) cos ω_m t, the maximum amplitude is M1 = $A_c + A_m$. Hence the modulation index is

$$m = \frac{A_m}{A_c} = \frac{8}{12} = \frac{2}{3}$$

with $M_2 = 0$, clearly, m = 1 irrespective of M_1

EXERCISE-O

SINGLE CORRECT TYPE QUESTIONS

1. Ans. (C) **2. Ans. (C)** **3. Ans. (A)** **4. Ans. (B)** **5. Ans. (B)** **6. Ans. (B)**
7. Ans. (A) **8. Ans. (B)** **9. Ans. (B)** **10. Ans. (A)** **11. Ans. (A)**

MULTIPLE CORRECT TYPE QUESTIONS

12. Ans. (A,B,D) **13. Ans. (B,D)**

EXERCISE-JM

1. Ans. (1) **2. Ans. (3)** **3. Ans. (3)** **4. Ans. (1)** **5. Ans. (2)** **6. Ans. (3)**
7. Ans. (2)

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8. Ans. (4) **9. Ans. (2)** **10. Ans. (4)** **11. Ans. (4)** **12. Ans. (1)** **13. Ans. (3)**
14. Ans. (4) **15. Ans. (4)**